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Computerized Diagnostic Analyzer for SSBN 726 Class Low Voltage DC Weapon Power System

by

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THESIS

COMPUTERIZED DIAGNOSTIC ANALYZER FOR
SSBN 726 CLASS LOW VOLTAGE
DC WEAPON POWER SYSTEM

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Thesis Advisor: Sherif Michael

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ABSTRACT

A need exists for a new test procedure for the Low Voltage DC (LVDC) Weapons Power System used to provide 28 volt DC power to various portions of the Fleet Ballistic Missile (FBM) Weapons System found on Ohio Class Submarines. The present test procedure does not provide sufficient information to assure that the system will function with the required reliability. This project involved the design and implementation of a test system which would perform the following functions: 1) accurately monitor the performance of the 28 volt LVDC rectifiers in the FBM Weapons System, 2) indicate when a system failure has occurred, 3) provide information to assist in trouble shooting, 4) provide facilities for database storage and analysis. This system is portable, user friendly, and compatible with current test requirements.

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I. INTRODUCTION

The 28 Volt/18 Kilowatt rectifier in the Low Voltage DC (LVDC) Weapons Power System is designed to provide ripple free DC power to the Fleet Ballistic Missile Weapons System. Low levels of ripple voltage can result in the degradation of the LVDC loads due to heat resulting from circulating alternating currents. Each FBM submarine has two of these units. Both units are required to be operational for System Initial Performance (SIP), and one unit is required to be operational for System Minimum Performance (SMP). Current test procedures are inadequate to insure the operational reliability of these rectifiers. Proven methods of digital signal processing can be used to accomplish the following:

1) Insure the unit is functioning within the manufacturer's and the U.S. Navy's specifications.

2) Assist technicians in the troubleshooting process by using spectral analysis to identify component failures.

3) Provide an on board database that allows the technician to anticipate required maintenance prior to an actual system failure.

The current procedure [Ref. 1:pp. 1-15] requires the technician to read the maximum and minimum value of the

voltage on the output side of the rectifier using an oscilloscope and standard probe. The percent ripple is then calculated using the following equation:

$$\%Ripple = \frac{(V_{max} - V_{min})}{V_{dc}} * 100\% \qquad (1.1)$$

Percent ripple voltage and current are then recorded as the results of the test. The maximum allowable ripple voltage is 2% RMS [Ref. 2:pp. 1-2]. This test procedure suffers from the following deficiencies:

1) Only two points (the maximum and the minimum) are used to evaluate the operational status of the rectifier.

2) By requiring the technician to read the maximum and minimum values from the oscilloscope screen an additional source of error is introduced.

3) No frequency information is provided by this test, thereby limiting the effectiveness of the trouble shooting data provided by the manufacturer.

4) Harmonic distortion, a key indicator of the operational integrity of the rectifier, is not monitored.

The Submarine Monitoring, Maintenance, and Support Office (SMMSO) recognized these problems and contracted the Idaho National Engineering Laboratory to study the feasibility of a computerized diagnostic analyzer for the 28 Volt LVDC rectifiers. This study culminated with an informal report,

EGG-EE-7941 [Ref. 3], issued May 1988. This informal report [Ref. 3:p. 17] states that:

> "...both with the introduction of controlled faults, and during normal operation, varying amplitude frequency harmonics of 60 Hz, 120 Hz, 180 Hz, 240 Hz, 300 Hz, and 360 Hz were present on the output of the rectifier. The amplitude of these harmonics vary depending on the introduced fault and the current load...Monitoring harmonic content (spectral density) of the DC output voltage will provide valuable information as to the overall operation of the unit and aid in component failure trouble shooting. The lack of harmonic content historical data and conflicting specifications governing their application make it difficult at best to develop specific harmonic content criteria for these rectifiers."

This paper uses the findings of this informal report as the basis for the development of a Computerized Diagnostic Spectral Analyzer (CDSA) for the SSBN 726 28 Volt LVDC rectifiers. The project summarized by this report involved the integration of the Rapid Systems R1405 Digital Oscilloscope package, a Zenith 386 Turbosport lap top computer, PC-MATLAB, and Lotus 1-2-3 release 2.2.

The Rapid System R1405 Digital Oscilloscope package and the Zenith 386 Turbosport computer take the place of the standard oscilloscope currently used for the present test procedure. The electrical connections to the digital oscilloscope are the same as for a standard oscilloscope. The R1405 provides a standard oscilloscope display of the voltage as a function of time, while at the same time generating a binary formatted file of the analog voltage signal. The Rapid Systems R900 translation program generates an ASCII file from

the binary file. This file is translated into a PC-MATLAB file by the PC-MATLAB translation program. PC-MATLAB calculates the parameters listed in Table 1.1.

TABLE 1.1 CDSA MONITORED PARAMETERS

PARAMETER	UNIT	MAX	MIN
DC VOLTAGE	VOLTS	30.5	26.5
RIPPLE VOLTAGE	%	2.0	N/A
SKEWNESS	NONE	*	*
KURTOSIS	NONE	*	*
60 HERTZ HARMONIC	% DC	*	*
120 HERTZ HARMONIC	% DC	*	*
180 HERTZ HARMONIC	% DC	*	*
240 HERTZ HARMONIC	% DC	*	*
300 HERTZ HARMONIC	% DC	*	*
360 HERTZ HARMONIC	% DC	*	*
TOTAL HARMONIC DIST.	% 60 HZ	5	N/A
120 HZ HARMONIC DIST.	% 60 HZ	3	N/A
180 HZ HARMONIC DIST.	% 60 HZ	3	N/A
240 HZ HARMONIC DIST.	% 60 HZ	3	N/A
360 HZ HARMONIC DIST.	% 60 HZ	3	N/A
360 HZ HARMONIC DIST.	% 60 HZ	3	N/A
POWER SPECTRAL DENSITY FOR 60, 120, 180, 240,300, AND 360 HZ	Db	*	*

* operating limits yet to be determined

There are two types of parameters listed in Table 1.1, time series parameters and spectral parameters. DC voltage, ripple, skewness, and kurtosis are the time series parameters calculated using the un-manipulated voltage data. Harmonic amplitude percentages, harmonic distortion, and power spectral density are calculated using the fast Fourier Transform of the voltage data. The object is to obtain a significant data base on each of these parameters and identify those parameters which correlate best with system and component failure. The numerical values obtained will be transferred to Lotus 1-2-3. Here the data base will be maintained, and trend analysis performed, using installed features of Lotus 1-2-3.

While the process seems complicated, all programs are menu driven and the operator is given step by step instructions. The entire analysis process takes less than 30 minutes and the results are saved to disk for future analyses by NAVSEA. Only a basic understanding of computers is required to run this test. The advantages of this procedure include the following:

1) The ability to determine accurately when system failure has occurred.

2) The ability to link abnormal findings to trouble shooting procedures.

3) The ability through trend analysis to predict impending system failure prior to a critical parameter being exceeded and the associated equipment degradation.

4) The ability to maintain an accurate record of past system performance.

Figure 1.1 shows the flow between the various programs and the file format required for the particular procedure.

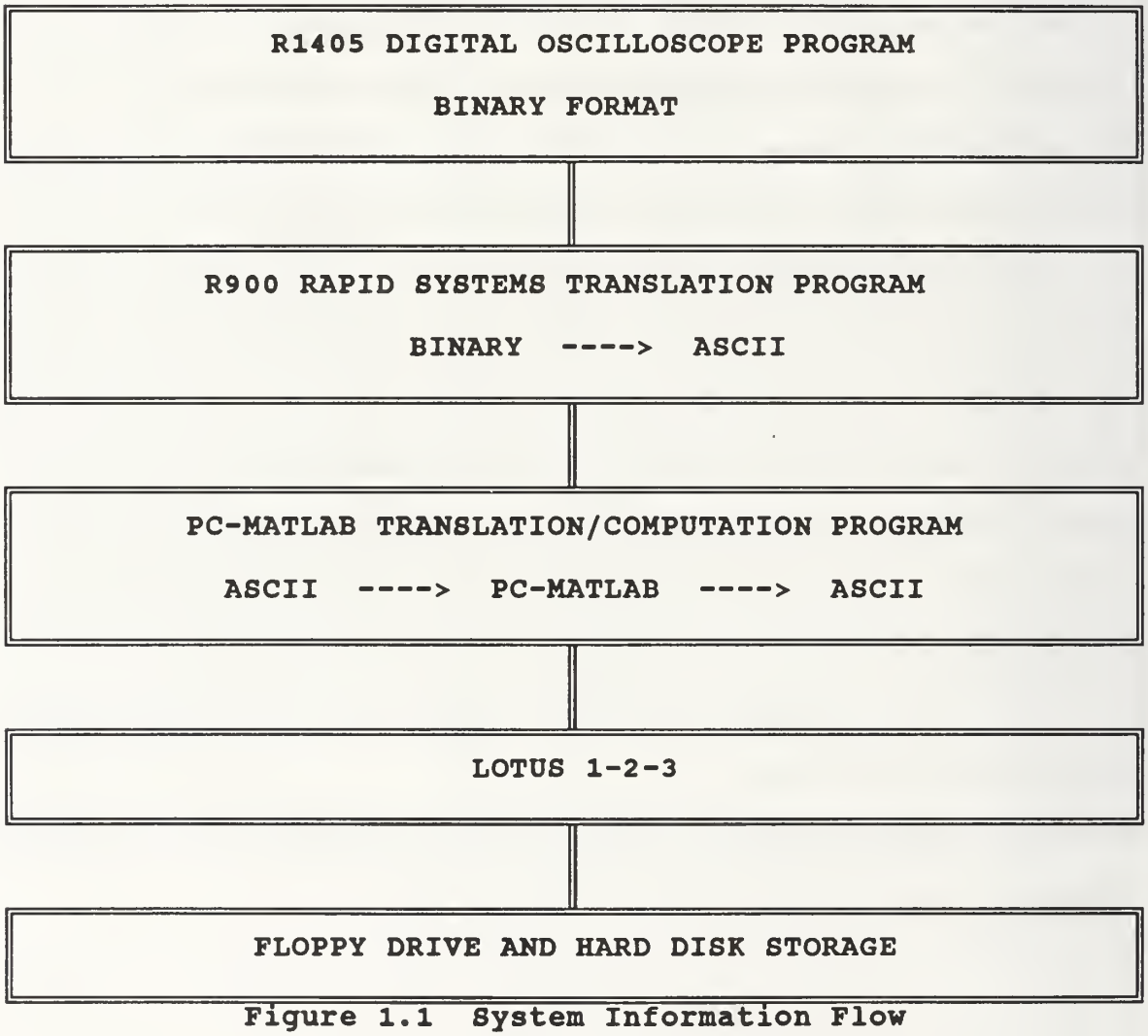

Figure 1.1 System Information Flow

This procedure will lead to decreased system down time, increased system reliability, reduced system maintenance costs, and enhanced technician efficiency. This method will also allow NAVSEA and SMMSO to maintain an accurate database on this equipment.

II. LVDC RECTIFIER DESCRIPTION AND MODE OF FAILURE

A. RECTIFIER DESCRIPTION

The 28 Volt, 400 Amp rectifier discussed in this paper is the Teledyne-Inet model 4D1450 Type I, found on Ohio Class Fleet Ballistic Missile Submarines. The ACME RE42174 rectifier found on older FBM submarines operates on the same principle as the Teledyne rectifier, so this test procedure may be modified for use on the older rectifiers.

The power supply combines an analog voltage sensing circuit and silicon controlled rectifiers (SCR's) to provide a regulated source of DC voltage. The rectifiers receive power from the 440 Volt, 60 Hz weapons system control and distribution switchboards. The two 400 Amp rectifiers supply power to the missile launcher control group and the rotary select switches for the Ship's Inertial Navigation System.

The rectification process is as follows: Ships 440 Volt, 60 Hz AC power is reduced to approximately 35 Volts AC for rectification. This low voltage AC is supplied to the SCR bridge rectifier circuit. The power SCR's in the bridge circuit are gated by SCR driver circuits, which receive their bias signal from a phase control circuit. The output of the bridge rectifier circuit is applied to an output filter

composed of capacitors producing a regulated DC output. Table 2.1 provides the manufactures reference data on the Teledyne rectifier.

TABLE 2.1 MANUFACTURES REFERENCE DATA

ITEM	DATA
Manufacturer	Teledyne-Inet
Type	Type I, 400 Ampere regulated DC Power Supply
Input Voltage	440 Volt AC, Three Phase
Input Frequency	60 Hz +/- 5%
Output Power	1.8 KW (maximum continuous)
Ripple Voltage	2 % RMS 6 % peak to peak
Load Type	Inductive and resistive
Heat Dissipation	800 Watts at 70 % efficiency
Maximum Output Current	400 Amps (cont.) 600 Amps (limit)

B. MODE OF FAILURE

There are two primary causes of failure in the Teledyne rectifier [Ref. 4:pp. 3-33]. The first, and most frequent, cause of failure has been attributed to the aging, and subsequent deterioration of capacitors in the output filter. The other cause of failure has been attributed to the breakdown of the output bus network, which causes a higher resistance in the network, and effectively changes the impedance of the output filter.

Capacitor failure will result in isolated thermal and electrical transients associated with circulating AC currents. There will be an increase in the harmonics of 60 Hz in the output of the rectifier signal in the early stages. The amount of each harmonic will depend on which capacitor in the output filter is failing, and the degree to which it has deteriorated. In the final stages the output filter circuit deteriorates rapidly due to the increased heat resulting in cascade failure of the surrounding components.

In the breakdown of the output bus network thermal transients will cause an increase in all harmonics of 60 Hz due to thermal damage of multiple capacitors. This type of failure, though less common, will proceed more rapidly than isolated capacitor failure, due to the higher temperatures

involved. In the latter stages the harmonics of 60 Hz become less distinct than the noise component.

III. COMPUTERIZED DIAGNOSTIC SPECTRAL ANALYZER

This chapter gives a description of the hardware and software used in the Computerized Diagnostic Spectral Analyzer (CDSA) proposed as the test system for the SSBN LVDC 28 Volt rectifier. The goals of the project require that a substantial amount of information be stored and analyzed so that the operational status of the rectifier can be accurately determined. The system is required to perform complex mathematical operations and at the same time be user friendly. These two goals often conflict with each other, and the final product strikes a balance between the two.

A. HARDWARE

The system was designed to minimize changes in the current test procedure, while enhancing the information obtained on the rectifier. Features required of the CDSA include:

1) The ability to process data in near real time so the information can assist on-board technicians.

2) Extensive storage capacity available so that a large data base can be maintained.

3) Installed batteries allowing the system to operate independently of ship's power.

The two units which make up the CDSA are the Zenith 386 Turbosport lap-top computer, and the Rapid Systems R1405

digital oscilloscope. This combination creates a two channel, PC-based, fully functional digital oscilloscope, with installed signal processing capability.

The computer is equipped with a 40 Mbyte hard drive, math co-processor, and three slot expansion kit. Any similarly equipped 286 or 386 lap-top computer can be used for this system. The principle reason for using lap-top computers is that they run on installed battery packs, and thus are can be set up anywhere free of cumbersome power cables. The installed hard drive on the Zenith allows for ample storage for operating programs and data. The Zenith 386 Turbosport has rechargeable nickel cadmium batteries which will allow 2 hours of operation without a recharge. Specific information on the Zenith 386 Turbosport lap-top computer is available in the Operators Guide [Ref. 5].

The Rapid Systems R1405 Digital Oscilloscope is a fully functional oscilloscope. Sample frequencies range from 50 Hz to 100 Khz. It stores the analog voltage signals in a binary format on floppy disks or the hard drive. Specifics about this hardware may be found in the R1405 Digital Oscilloscope Operators Guide [Ref. 6].

B. SOFTWARE

The CDSA requires the use and integration of 5 separate software packages:

1) R1405 Digital Oscilloscope Software
2) Rapid Systems R900 Translation Program
3) PC-MATLAB Translation Program
4) PC-MATLAB Program
5) Lotus 1-2-3 Release 2.2

The Rapid Systems programs are located in the R1405 directory, the PC-MATLAB programs are found in the MATLAB directory, and the Lotus 1-2-3 programs are found in the 123 directory. Information is transferred between the various programs by a floppy disk which is saved at the end of the test. This floppy will contain the results from each program in an ASCII format.

The time series capabilities of the R1405 Digital Oscilloscope Peripheral are implemented in the R1405 software. A time series waveform can be paused, scrolled in any direction, and compressed or expanded to full scale. The two channels can acquire from 1 to 65,022 samples points. For the CDSA a standard set-up file is loaded each time the R1405 program is accessed. This set-up file sets the oscilloscope parameters required to place the output data file in the proper format for further processing.

The Rapid System's R900 File Translation Utility converts data files saved by Rapid System's R1405 Digital Oscilloscope

Program to a format that can be translated by PC-MATLAB and read by Lotus 1-2-3. This program is easy to use and requires only a few key strokes. The program is started by typing R900 and menus instruct the operators through the conversions.

PC-MATLAB takes an input in the form of a matrix and performs mathematical operations on the contents. The results can be displayed in the form of tables or graphical representation. The MATLAB "function" allows complex mathematical operations to be performed on matrices with a few key strokes. MATLAB combines numerous math and statistical functions with extensive graphics capability.

Lotus 1-2-3 is a powerful spread sheet program. It has numerous built in features for the manipulation of data base information and extensive graphics functions. It is widely used throughout the U.S. Navy and there is extensive documentation on its use.

IV. METHODS OF DATA ANALYSIS

This chapter outlines the procedures and equations needed to calculate the parameters used in the CDSA. The analog voltage signal observed at the DC output of the rectifier is described by equation 4.1.

$$V_t = V_{dc} + V_{60} + V_{120} + V_{180} + V_{240} + V_{300} + V_{360} + V_{noise} \tag{4.1}$$

The DC voltage has a nominal value of 28 volts and is maintained constant by the voltage control unit. The harmonics of 60 Hz are present under normal operating conditions but their levels are elevated in the presence of system faults. Noise is a random voltage signal usually several orders of magnitude less than the DC voltage or the harmonics of 60 Hz. This signal will be analyzed using classic methods of time series analysis and frequency analysis. All the operations described in the next two sections are performed by the PC-MATLAB program, using data taken from the digital oscilloscope.

A. TIME SERIES ANALYSIS

When a series of data points has a tendency to cluster around some particular value (i.e., DC voltage) then it is useful to characterize the data set by a much smaller set of numbers. The five statistical parameters calculated from the 2048 (N)data points of the analog voltage signal are the mean, variance (second moment), standard deviation (ripple voltage), skewness (third moment), and kurtosis (fourth moment).

The mean measures the value around which clustering occurs. This is the average of the rectified voltage signal (V_{dc}). This is calculated as shown in equation 4.2.

$$MEAN = \frac{1}{N} * \sum_{n=1}^{N} x(n) \qquad (4.2)$$

Variance indicates the variability of a sample set x(n), around the mean. Standard Deviation (std) estimates the mean square deviation of x(n) from its mean value. These are described in equations 4.3 and 4.4 respectively.

$$VARIANCE = \frac{1}{N-1} * \sum_{n=1}^{N} [x(n) - MEAN]^2 \qquad (4.3)$$

$$std = \sqrt{VARIANCE} \qquad (4.4)$$

Skewness characterized the degree of symmetry of the data set around its mean. It is a pure number that characterizes only the shape of the distribution. It is calculated using equation 4.5.

$$SKEWNESS = \frac{1}{N} * \sum_{n=1}^{N} \left[\frac{x(n) - MEAN}{std} \right]^3 \qquad (4.5)$$

Kurtosis is a measure of the relative "peakedness" or "flatness" of a distribution. It is defined in equation 4.6.

$$KURTOSIS = \frac{1}{N} * \sum_{n=1}^{N} \left[\frac{x(n) - MEAN}{std} \right]^4 \qquad (4.6)$$

B. FREQUENCY ANALYSIS

The equations described in this section make use of the PC-MATLAB fft(x) function to generate the transform of the data set x(n) described by equation 4.7.

$$X_{k+1}=\sum_{n=0}^{N-1} x(n+1)*W_N^{kn} \quad where \quad W_N=e^{-j(2\pi/N)} \qquad (4.7)$$

The series is written in an unorthodox way, running over n+1 and k+1 instead of the usual n and k because MATLAB functions run from 1 to N instead of from 0 to N-1. The FFT function is used to find the frequency components of a signal buried in a noisy time domain signal. We can further use this to find the power spectral density, a measure of the energy of the various frequencies, and the Harmonic Distortion of the signal, the ratio of the higher order harmonics to the primary.

1. Sampling Parameters

The sampling parameters are those settings for the R1405 oscilloscope that will align it for the harmonics of 60 Hz up to 360 Hz. These parameters are sample frequency , sample size , and frequency resolution. The factors that determine the values set for these parameters are maximum frequency of interest, resolution desired and equipment characteristics of the R1405 oscilloscope.

The maximum frequency of interest for the 28 volt rectifiers is 360 Hz. The required sample frequency can be calculated using equation 4.8. The closest R1405 setting

$$f_s = 2 * f_{max} = 2 * 360 = 720 Hz \tag{4.8}$$

greater than 720 Hz is 1000 hz, therefore the sample frequency is set at 1000 Hz.

Sample size is dependent on the desired frequency resolution. The input frequency into the rectifier can vary by as much as 2% (1.2 Hz) and still be within the manufacturer's specifications. Sample frequency has been set at 1000 Hz and the maximum sample size for the R1405 is 2048 points. From this we can calculate the maximum resolution of the R1405 at 1000 Hz using equation 4.9. As sample size is increased the time required

$$\Delta f = \frac{f_s}{N} = \frac{1000}{2048} = .4882 Hz \tag{4.9}$$

to perform these calculations is also increased. It takes approximately 3 minutes longer to perform these calculations using a 2048 sample size as compared with a 1024 sample size. The increased resolution justifies the increased computation time.

These parameters are entered into the system and then saved as a set-up file that is loaded every time the R1405 program is accessed. The associated PC-MATLAB functions have been specifically designed with these parameters as a basis so any alteration in this set-up file will result in erroneous results. Table 4.1 lists the vital parameters which should be checked each time the R1405 program is accessed.

TABLE 4.1 DIGITAL OSCILLOSCOPE VITAL PARAMETERS

SAMPLE SIZE	2048 POINTS
SAMPLE FREQUENCY	1 Khz/20 msec
ACTIVE CHANNEL	A

2. Harmonic Content Calculations

To calculate the harmonic content of the digital voltage signal obtained and saved from the R1405 program we must first take the fft of the sample set. We do this using the PC-MATLAB function fft(x) described above. We then take the absolute value of this new sample set because we are only interested in the magnitudes. Since we are measuring the output of a DC rectifier the 0 frequency component will be the largest constituent of the signal spectrum. We identify the magnitude of this component and compare it to the magnitude of the various harmonics of 60 Hz using equation 4.10.

$$\%HARMONIC = \frac{harmonic_{60Hz}}{0_{freq}component} * 100\% \quad (4.10)$$

We now encounter the problem of normal frequency variation at the input of the rectifier. Input to the rectifier can vary between 57 Hz and 63 Hz according to the manufactures specifications. This will cause the harmonics of 60 Hz not to occur exactly on a multiple of 60 Hz. To counter this we look at the maximum value in a range surrounding the harmonic of interest. Table 4.2 lists the harmonics of interest and search ranges.

TABLE 4.2 HARMONIC SEARCH RANGES

HARMONIC	MIN	MAX
60 Hz	57 Hz	63 Hz
120 Hz	114 Hz	189 Hz
180 Hz	171 Hz	189 Hz
240 Hz	228 Hz	252 Hz
300 Hz	285 Hz	315 Hz
360 Hz	342 Hz	378 Hz

The amplitude of the harmonics of 60 Hz exceed the amplitude of other frequencies during normal operation and under fault conditions [Ref. 3:p. 17]. By scanning an interval around the harmonic of interest and taking the maximum we take into account the frequency variation of the

input signal. Another benefit of scanning an interval and retaining the maximum is that we reduce the size of the spectral sample set from 1024 elements to 6, thus reducing the required storage capacity of our database. This makes database management simpler, and computations within Lotus 1-2-3 faster with no loss of vital information.

3. Harmonic Distortion

In terms of the overall health of the rectifier, the harmonic signature of the system offers much more refined data which may be related to the operational characteristics of the rectifier than does ripple voltage. Harmonic distortion results from frequencies other than the fundamental frequency. The Harmonic Distortion Factor for one harmonic and multiple harmonics are given in equations 4.11 and 4.12 respectively.

$$hdf = \sqrt{\frac{|harmonic|^2}{|fundamental|^2}} * 100 \qquad (4.11)$$

$$hdf_{total} = \sqrt{\frac{\sum_{h=2}^{h=6} |X_{60*h}|^2}{|fundamental|^2}} \qquad (4.12)$$

MIL-STD-1399(NAVY) [Ref. 7] and S9314-BD-MMA-010 [Ref. 8:p. 2] site the performance specifications applicable to 440 volt AC, 2 phase, 60 Hz applied input voltage listed in Table 4.3

TABLE 4.3 RECTIFIER HARMONIC PERFORMANCE SPECIFICATIONS

SPECTRAL CONTENT	SPECIFICATION
NOMINAL FREQUENCY	60 Hz
FREQUENCY TOLERANCE	5 %
TOTAL HARMONIC DISTORTION	5 %
SINGLE HARMONIC DISTORTION	3 %

Monitoring the harmonic distortion factor of the 28 volt Teledyne rectifier will provide valuable information as to its overall operation and aid in component failure troubleshooting. The lack of harmonic distortion historical data and conflicting specifications governing their application make it difficult to associate a particular component failure with this factor. Once a historical data base is developed particular component failures may be associated with particular relationships between the seven harmonic distortion factor parameters. This relationship can be used to determine the relative condition and operation of the diodes and SCR's in the circuit bridge. For this factor to give a true indication of system operation we will also

have to develop baseline data on the input AC signal. This will involve analysis of the SSTG output.

4. Power Spectral Density

Damage to the rectifier is caused by the thermal and electrical transients generated by circulating AC currents in the rectifier. These circulating AC currents are transmitted to the dependent loads thus the damage is not limited to the rectifier itself.

The total power in a signal is the same whether we compute it in the time domain or in the frequency domain. This relationship is described by equation 4.13 which is known as Parseval's theorem:

$$POWER_{TOTAL} = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df \qquad (4.13)$$

We are interested in the power contained in the frequency interval surrounding the harmonics of 60 Hz. This represents the significant portion of the power affecting the rectifier.

The CDSA will use the Periodogram method to estimate the Power Spectral Density (PSD) of the voltage signal. The Power Spectral Density is defined as the Fourier transform of the autocorrelation function of a signal [Ref. 9:pp. 542-550],

where the autocorrelation function, eq. 4.14, gives an indication of the relationship between samples in a data set.

$$R_x(l) = \frac{1}{N}\sum_{n=1}^{N-|l|} x(n) * x(n+|l|) \qquad -N \le n < N \tag{4.14}$$

To estimate the power spectral density from the autocorrelation function the Fast Fourier Transform is used (eq. 4.15).

$$psd(freq) = \sum_{l=-N+1}^{N-1} R_x[l] * e^{-j(2\pi * freq * l)} \tag{4.15}$$

If equations 4.13 and 4.15 are examined it becomes apparent that the power spectral density is proportional to the magnitude squared of the fft of the original data set. Equation 4.16 gives the estimate of the power spectral density (psd) and equation 4.17 gives PSD in decibels (PSD_{Db}).

$$psd(freq) = \frac{1}{N} * |fft(x(n))|^2 \tag{4.16}$$

$$PSD_{dB}=20*\log(psd(freq)) \tag{4.17}$$

PSD is used as an index of rectifier function because the power associated with a DC supply and an a AC ripple cannot easily be individually calculated and added together to determine the impact on the rectifier and associated loads. The mathematics involved in analyzing both DC and AC power simultaneously are laborious and not practical for this application. To accurately calculate this would require us to consider specific frequencies associated with noise pulses and their harmonics, bandwidth, power factor, load resistance, impedance, and AC RMS ripple voltage.

PSD does not give us the actual thermal power applied to the rectifier and associated loads. PSD does give us a parameter related to the power associated with the principle frequency components responsible for damage. PSD thus gives an index associated with AC thermal loads on the rectifier.

C. PERFORMANCE CRITERIA

The overall condition of the LVDC weapon power system is assessed by comparison of the actual performance parameters with system performance criteria. If spectral monitoring had been implemented with rectifier installation then the initial performance criteria would establish the baseline values for

monitoring degradation over time. Since the rectifiers in the fleet have been operating for several years it becomes necessary to develop a data base of the 20 parameters monitored by the CDSA. Once a significant database of M points, composed of results from several operating units, is established the standard deviation (eq. 4.20) can be calculated.

$$\sigma = \sqrt{\frac{1}{M-1} * \sum_{j=1}^{M} (p_j - p_{mean})^2} \qquad (4.18)$$

where $p_j \equiv$ *monitored parameter*

If we assume a Gaussian type distribution we can classify any parameter exceeding twice the standard deviation as abnormal from the statistical frame of reference. While this will not necessarily indicate that the rectifier is failing, it does justify additional monitoring.

1. Parameter Correlation with System Damage

The question now arises as to how to correlate these parameters with system failure and degradation. We can of course examine the database information developed from the CDSA and over time see if increases in certain parameters occur with certain failures. This of course means that several rectifiers will be damaged why we are trying to develop performance criteria. A better method is to take a

parameter known to be associated with system degradation and perform linear correlation analysis using Pearson's r method [Ref. 10:p. 484] given by equation 4.19.

$$r = \frac{\sum_{i=1}^{M} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{M} (x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{M} (y_i - \bar{y})^2}} \qquad (4.19)$$

where x_i=ripple voltage y_i=measured parameter
$\bar{x}$ and $\bar{y}$ are the means of x_i and y_i respectively

The value of r lies between -1 and 1, inclusively. It takes on the value of 1, termed "complete positive correlation," when the data points lie on a perfect strait line with a positive slope. If the data points lie on a perfect straight line with negative slope, y decreasing as x increases, then r has the value -1; this is called "complete negative correlation." A value of r near 0 indicates that x and y are uncorrelated.

Ripple voltage is known to give a direct indication of rectifier performance and degradation. This is the parameter which will be used as the baseline for determination of correlation with the other parameters using Pearson's equation. If ripple voltage is high and increasing then the rectifier is not functioning properly and its material condition is degrading. This is a task that exceeds ship board capability but is within the capabilities of SMMSO.

2. Regression Analysis

The ultimate purpose of the CDSA is to warn the operator that the unit needs maintenance long before a failure occurs. To accomplish this task we must correlate operating hours with the 22 parameters measured. Lotus 1-2-3 has a linear regression function that calculates the constant and coefficient for a simple linear equation (eq. 4.20).

$$parameter_{(prediction)} = a + b * (t_{operating}) \tag{4.20}$$

The variables a and b are calculated using the operating hours since some predetermined start point (i.e., system installation or overhaul), observed values of the parameter in question, and a standard error of the parameter estimate which is calculated by Lotus 1-2-3. The operating hours (x_i) is a known quantity and the object of these calculations is to predict when a measured parameter will exceed some critical value. The following definitions and equations (eq. 4.21-4.23) describe the calculations performed by the Lotus 1-2-3 Linear Regression function.

y_i-measured value of the parameter
x_i-operating hours since baseline set
σ_i-uncertainty associated with y_i
M-Number of observations

$$S \equiv \sum_{i=1}^{M} \frac{1}{\sigma_i^2}, \quad S_x \equiv \sum_{i=1}^{M} \frac{x_i}{\sigma_i^2}, \quad S_y \equiv \sum_{i=1}^{M} \frac{y_i}{\sigma_i^2}$$
$$S_{xx} \equiv \sum_{i=1}^{M} \frac{x_i^2}{\sigma_i^2}, \quad S_{xy} \equiv \sum_{i=1}^{M} \frac{x_i y_i}{\sigma_i^2} \tag{4.21}$$
$$\Delta \equiv S * S_{xx} - (S_x)^2$$

$$a = \frac{S * S_{xx} S_y - S_x S_{xy}}{\Delta} \tag{4.22}$$

$$b = \frac{S * S_{xy} - S_x S_y}{\Delta} \tag{4.23}$$

All of the above calculations are performed using data stored in Lotus 1-2-3, and the built in regression function. This function also calculates the value of r squared, which is merely the value of equation 4.19 squared, and the error in the independent variable coefficient. If the standard error of the Y-estimate is greater than half the value of the constant (a) then the results of the linear regression are suspect. Specifics on these calculations may be found in *1-2-3 FOR SCIENTISTS AND ENGINEERS (Second Edition)* [Ref. 11:pp. 177-182]. Once the coefficients have been determined we can project when a parameter will exceed a critical value by using the equation to generate a graph like the one in Figure 4.1.

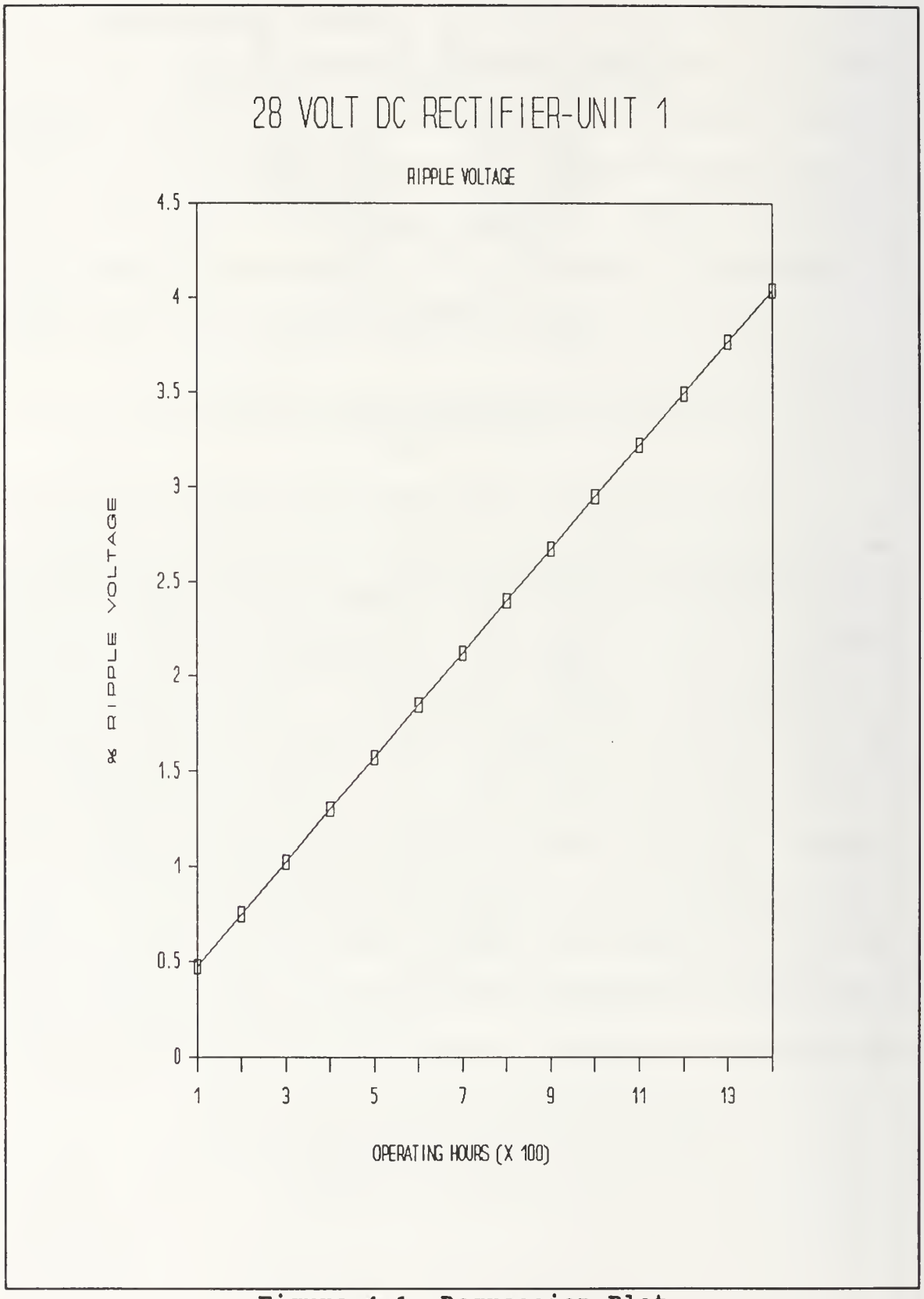

Figure 4.1 Regression Plot

D. EFFECT OF RECTIFIER LOAD ON ANALYSIS

To determine the effect of rectifier load on frequency and harmonic distortion analysis an operating rectifier at the Kings Bay, Georgia Weapons Training Facility was examined. Only test equipment authorized for use on the 400 Ampere, DC Type I rectifier (Table 4.4) may be used to perform testing and trouble shooting [Ref. 2:pp. 5.1-5.4] on the Teledyne rectifier. This meant that a standard oscilloscope had to be used for this load testing and the data points had to be manually recorded from the oscilloscope screen. An fft was performed on the data, for several values of current, and a ratio was taken of the harmonic to the fundamental. These results are displayed in Figures 4.2 through 4.5.

These figures clearly demonstrate that the load on the rectifier effects the dominance of the various harmonics. For this reason it is suggested that the test be performed on the rectifier at normal operating load after a sufficient warm-up period. The normal load on the rectifiers will vary from unit to unit and from ship to ship. SMMSO will have to set guide lines for uniform testing procedures.

TABLE 4.5 TEST EQUIPMENT FOR 400 AMP TYPE I DC RECTIFIER

NAME	AN OR MFGR DESIGNATION	ALTERNATE	USE
Oscilloscope Mhz BW 10 Mv sensitivity	585A Tektronix Inc. 80009	Equivalent	Waveform analysis
Multimeter	AN-PMS-6	Equivalent	DC and AC voltage measurements
Circuit board Extender	23D838 Teledyne-Inet 90911	None	Aid in Trouble shooting circuit board assemblies

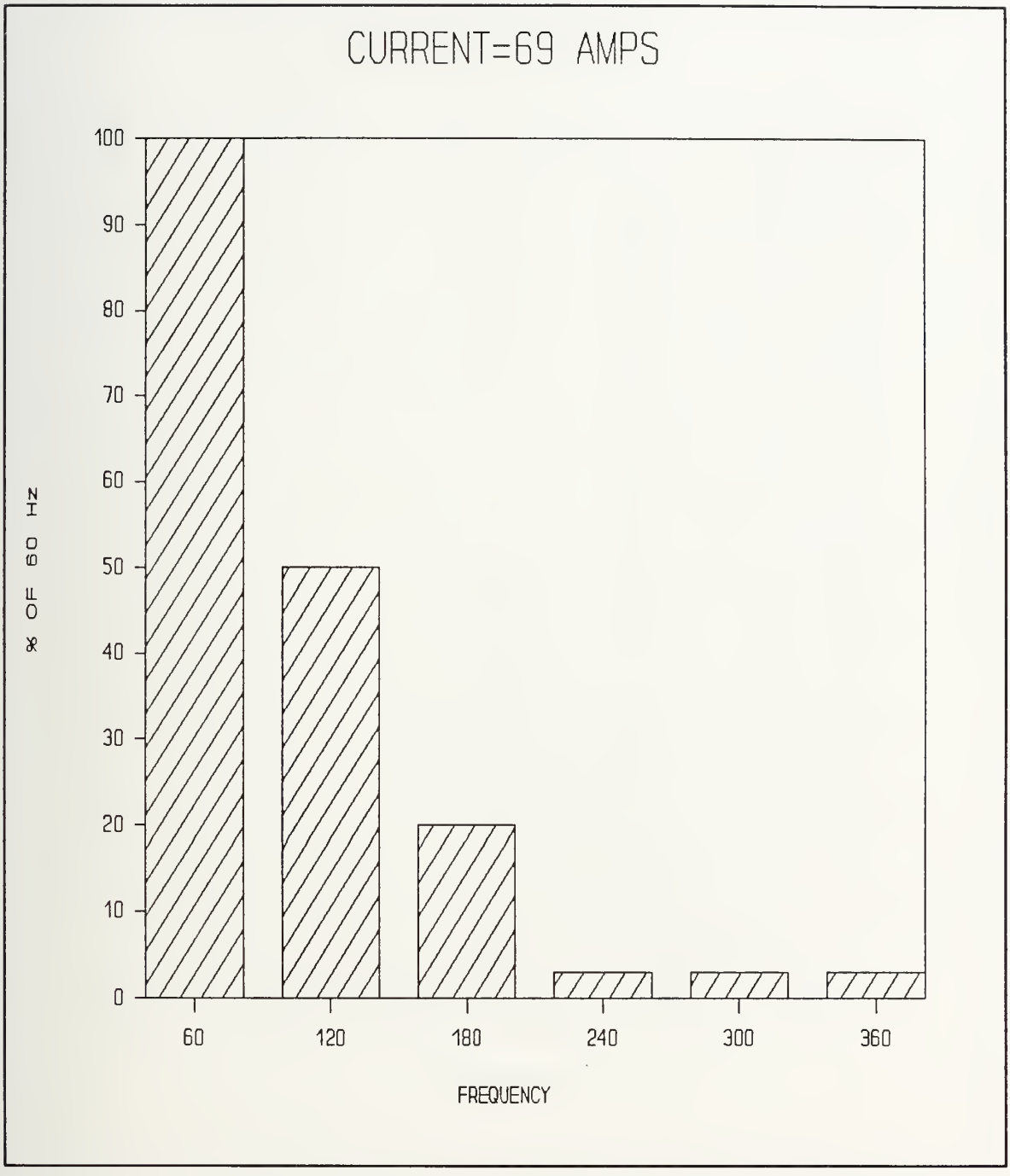

Figure 4.2 Harmonic Ratios with Current=69 amps

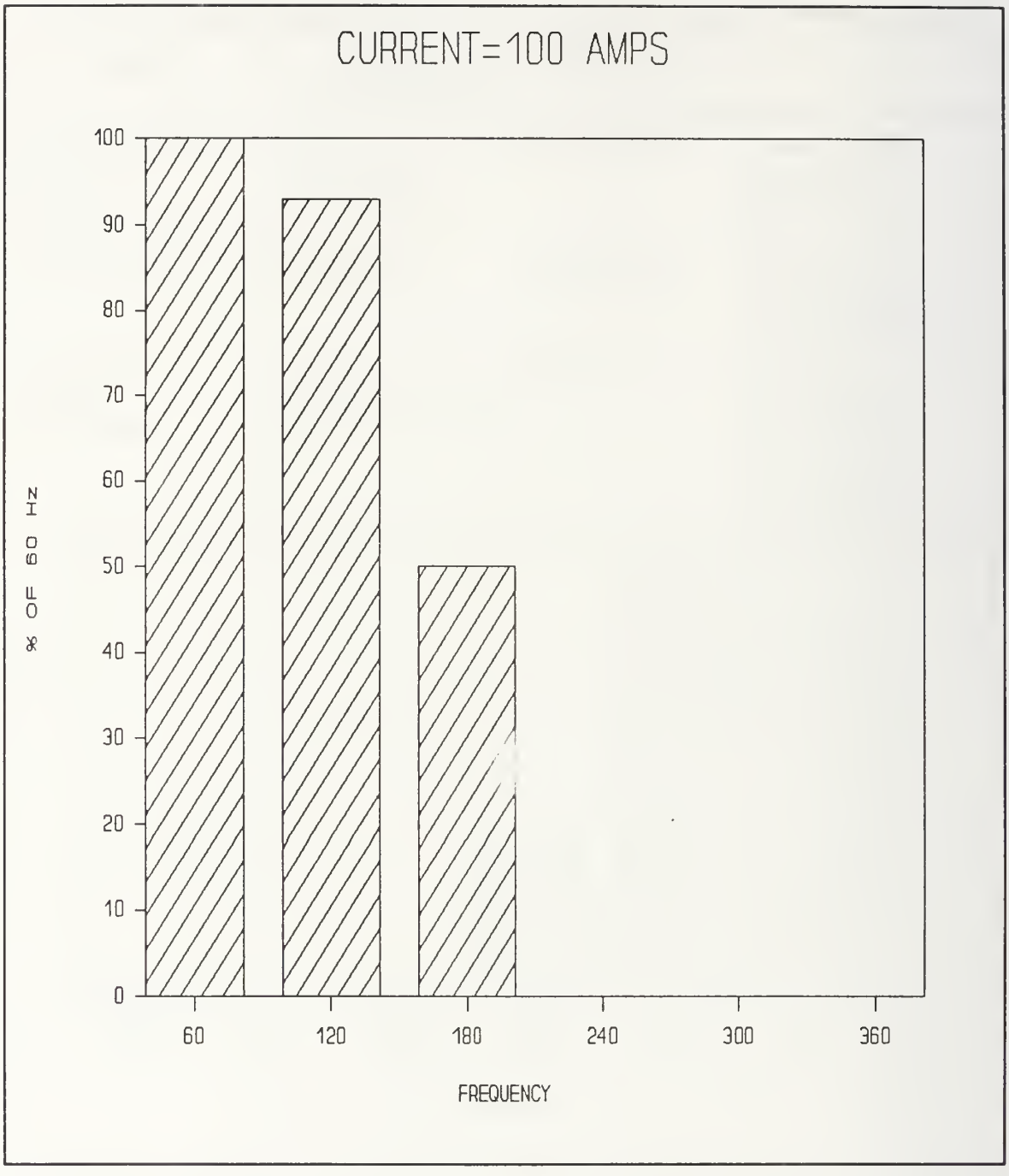

Figure 4.3 Harmonic Ratios with Current=100 amps

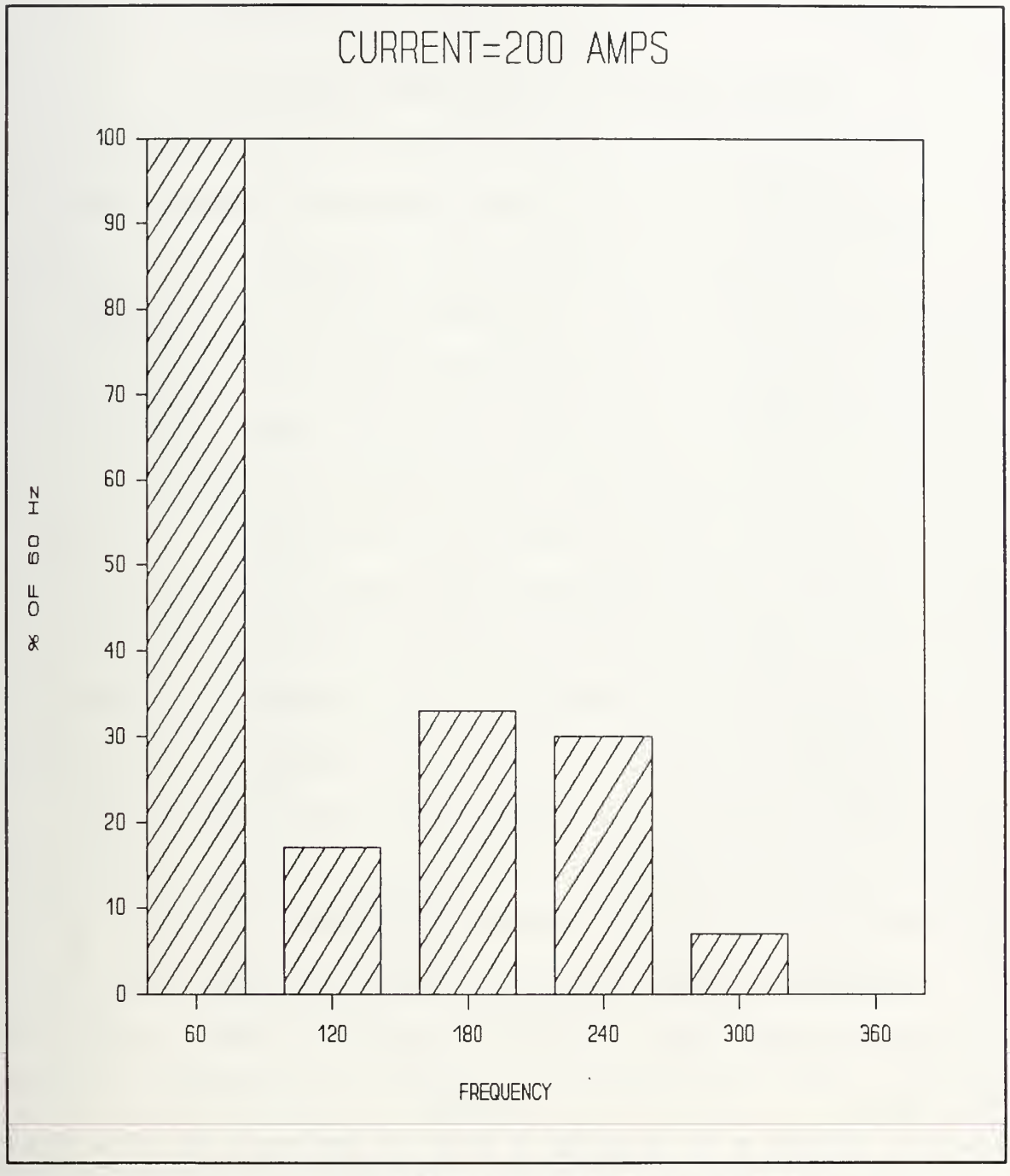

Figure 4.4 Harmonic Ratios with Current=200 amps

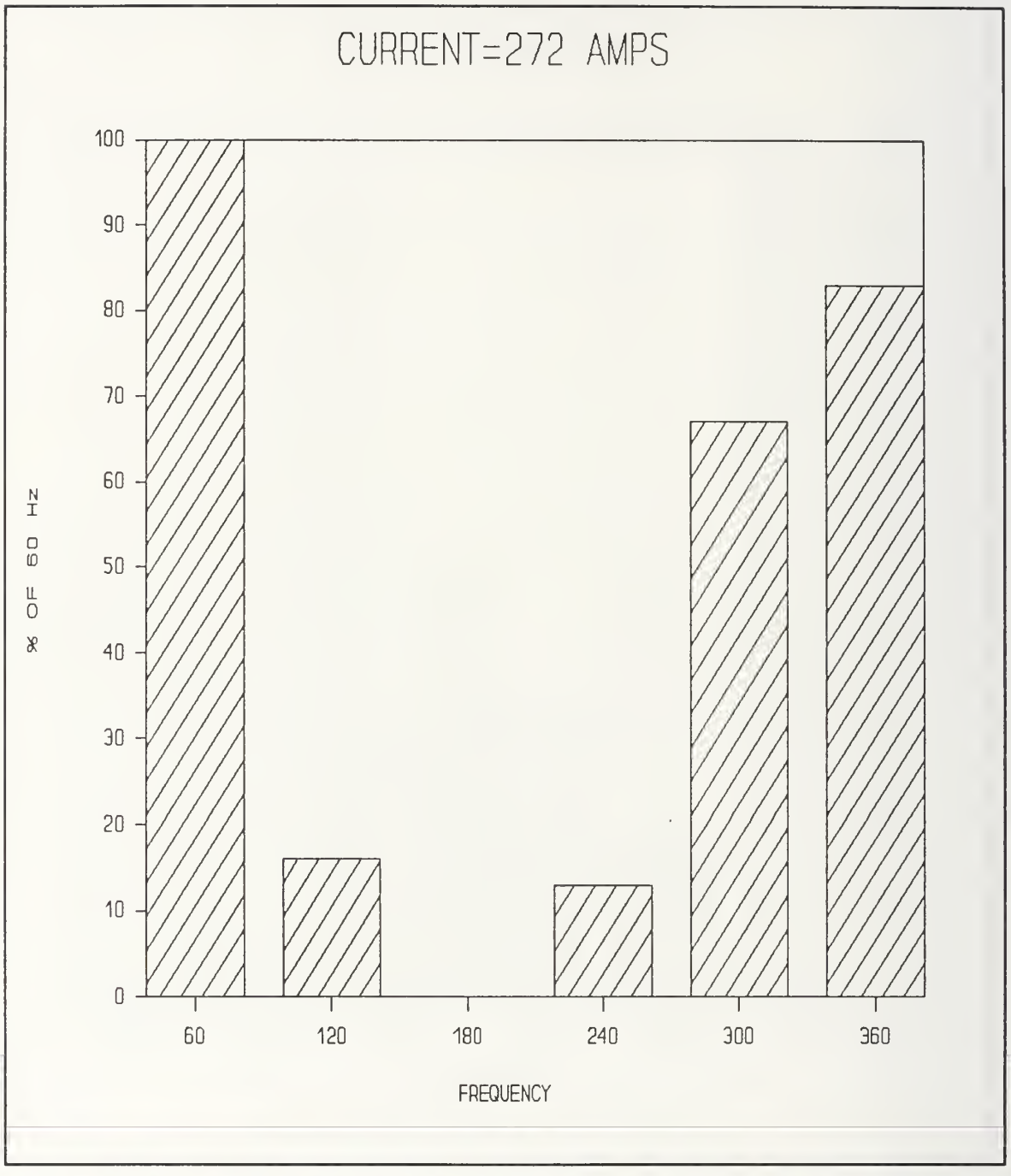

Figure 4.5 Harmonic Ratios with Current=272 amps

V. SYSTEM OPERATING INSTRUCTIONS

This section describes the operation of the CDSA and the proposed test procedure. All tasks mentioned herein should not be performed by any personnel with less qualifications than a third class petty officer having thorough knowledge of the equipment [Ref. 2:p. 4-1]. Operators will be required to have a general familiarity with the operation of personal computers. In regards to connecting the oscilloscope probe to the rectifier all safety and operational requirements of PMS and *NAVSEA Technical Manual 0910-LP-023-08900* shall be followed. The connection of the probe, warm-up time, and load condition for testing are covered by these two documents.

This chapter describes the set up and basic operation of the hardware and programs used in the CDSA. The CDSA requires a 286 or 386 IBM compatible personal computer, with expansion slots, the R1405 Digital Oscilloscope package (hardware and software), R900 Translation Utility, PCMATLAB Translation Utility, PCMATLAB, and LOTUS 1-2-3 release 2.2. The computer used will be required to have a minimum of 8 Mbytes storage available on the hard drive and at least one floppy drive. In addition PCMATLAB requires a math coprocessor to function.

A. RAPID SYSTEMS R1405 DIGITAL OSCILLOSCOPE

The operating manual gives detailed information on the installation and operation of the R1405 Digital Oscilloscope. This section gives an overview of the operating manual. Minimum system requirements are listed in Table 5.1.

TABLE 5.1 OSCILLOSCOPE SYSTEM HARDWARE REQUIREMENTS

-IBM PC, XT, AT or compatible computer with at least 640 KBytes of contiguous RAM, and one free expansion slot.

-At least one 3.5" or 5.25" floppy drive.

-IBM or compatible color graphics adaptor (CGA) card (EGA is supported in the CGA mode).

-Rapid Systems R1405 (2x64) Digital Oscilloscope Peripheral.

-Rapid Systems R1-11 standard interface card, which plugs into any expansion slot.

It is suggested that the operating manual for the Rapid Systems R1405 Digital Oscilloscope be reviewed prior to operating the system. Additional figures, simplifications, and modifications of operating instructions will be found in this section, therefore it is essential that installation be performed in accordance with this section.

1. Oscilloscope Installation

The R1405 Digital Oscilloscope Peripheral software resides on a 5.25 inch floppy disk (360K density). Files included on the source disk are listed in Table 5.2

TABLE 5.2 SOURCE DISK FILES

1.	R1405.EXE	Digital Oscilloscope Program
2.	4X6.FON	Used by the program to display graphics characters on the screen.
3.	ERROR.MSG	Displays Turbo Graphics error messages to the screen.
4.	I1405.COM	Initialization Program
5.	RS1405.SYS	Configuration file

All hardware insertion or removal should be done with the **COMPUTER POWER OFF.** The standard interface card contains static sensitive parts that can be damaged if inserted or removed when the power is on.

STEP 1. Turn the computer's power **OFF.**

STEP 2. Remove the cover of the computer to expose the expansion slots. Refer to the computer manual to insure the proper procedure. Locate an empty expansion slot and insert the R1-11 standard interface card, making sure the metal bracket and edge connector are to the rear of the computer.

NOTE: (1) On many lap top computers the expansion slots are exterior to the computer, so removal of the computer cover is not required.

(2) In some instances the metal bracket may require slight bending in order for the board to be properly installed.

STEP 3. Replace the computer cover.

STEP 4. Attach the DB-25 connector from the 2X64 to the connector on the R1-11 standard interface card.

STEP 5. Turn the computer power on and boot the system with MS-DOS version 2.11 through 3.1 or equivalent.

STEP 6. Locate the disk marked *Model R1405 Digital Oscilloscope Peripheral Software for IBM*. This disk is not copy protected. It is recommended that a backup copy is made and the original is stored in a safe place. Insert the backup copy in drive *A* (see note 3).

Note: (3) The installation described below is for a PC with the hard drive designated *C* and a floppy drive designated *A*.

STEP 7. When the DOS prompt *C:>* appears, type **MD\R1405 <Enter>.**

STEP 8. Type **CD\R1405 <Enter>.**

STEP 9. To copy the source files to the hard disk type **COPY A:*.* C:\R1405 <Enter>.**

STEP 10. Type **I1405.COM <Enter>.** Press any key. The screen displayed in figure 5.1 will appear. Check the displayed interface type to assure that it is set at *Standard (R1-11)*. If it is <u>not</u> type **T <Enter>.** The *Current configuration file* should be set at *RS1405*. If it is <u>not</u> press the **<Enter>** key and use the **<Up Arrow>** or the **<Down Arrow>** keys to select the appropriate configuration file.

STEP 11. Type **R1405** to run the software. The screen displayed in figure 5.2 will appear. The digital oscilloscope display will appear when any key is pressed. The installation is now complete.

```
                    I N T E R F A C E    O P T I O N S


  Current configuration file = A
  Current configuration path = C:\R1405
  Current configuration file = RS1405


  Current interface type     = Standard (RI-11) --Default--
  Current interface address  = 792 (Decimal)    --Default--


Press:     <T>   to change interface type.
           <-,-> to change interface address.
           <CR>  to save/retrieve configuration file.
           <ESC> to end program.
```

Figure 5.1 Initialization Screen

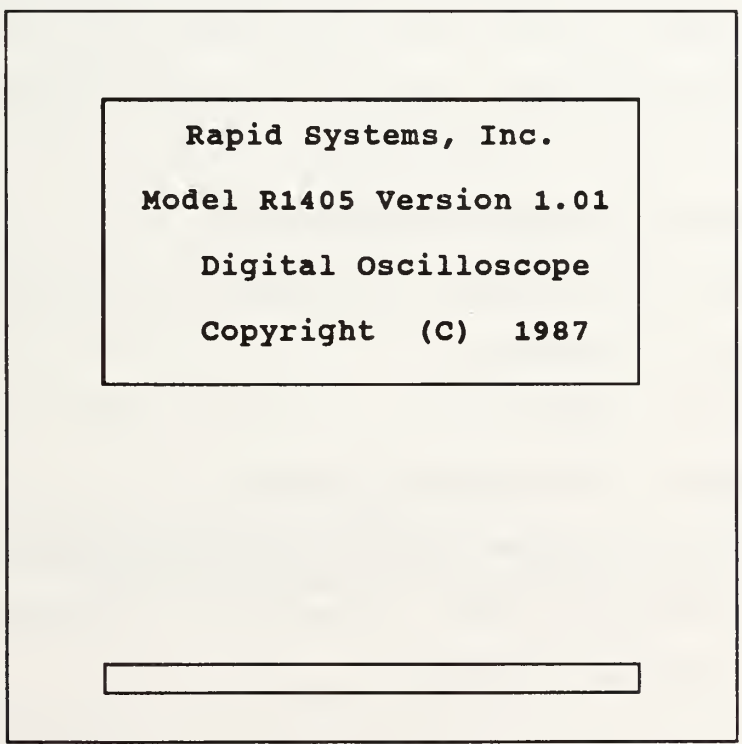

Figure 5.2 Oscilloscope Entry Screen

2. Oscilloscope Setup

This section describes how to align the oscilloscope for the test procedure. In depth descriptions of the various functions and capabilities of the oscilloscope may be found in the operating guide. Installation is assumed to have been completed as described above. A times one (X1) oscilloscope probe should be used to insure accurate gain scaling.

After invoking the R1405 software (by typing **R1405**) the Time Series Display (Figure 5.3) can be started by pressing any key. Pressing the **<Esc>** key twice terminates the program. The **<F1>** key brings up the General Options Menu (Figure 5.4). Pressing **<Ctrl>** and **<F1>** simultaneously will display the Time Series Options Menu. The values displayed in Figures 5.3 and 5.4 are the correct settings for the CDSA. While in the General Options Menu the Trigger Mode should be set to *AUTOMATIC* and the data file should be *A:\LVDC*. While in the Time Series Option Menu the following settings should be made:

a) Time period per division-*20 ms*

b) Volts per division on channel A-*5 volts per division*

c) Active Channel-*A*

d) Channel Display-*A*

e) Display view time-*0.0 seconds*

f) Pre/Post trigger Buffer Sizes-*2048 data points*

These settings should then be saved in a configuration file using **<F1>** followed by **<F6>**.

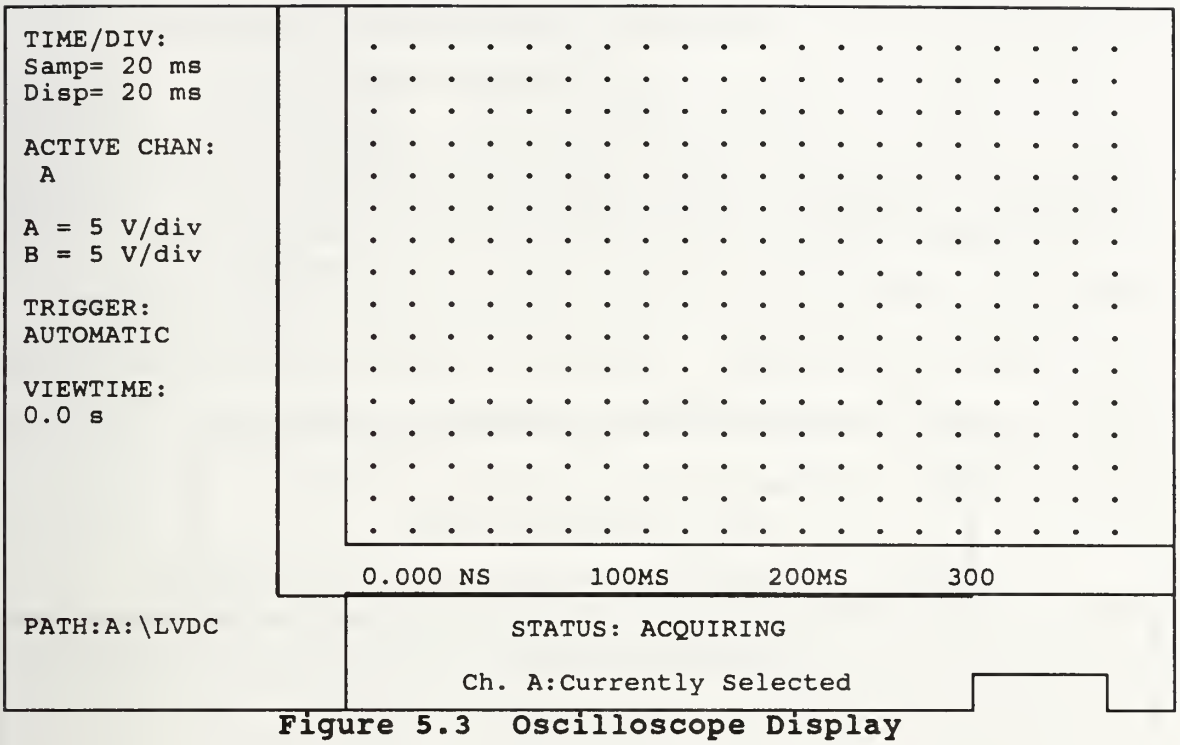

Figure 5.3 Oscilloscope Display

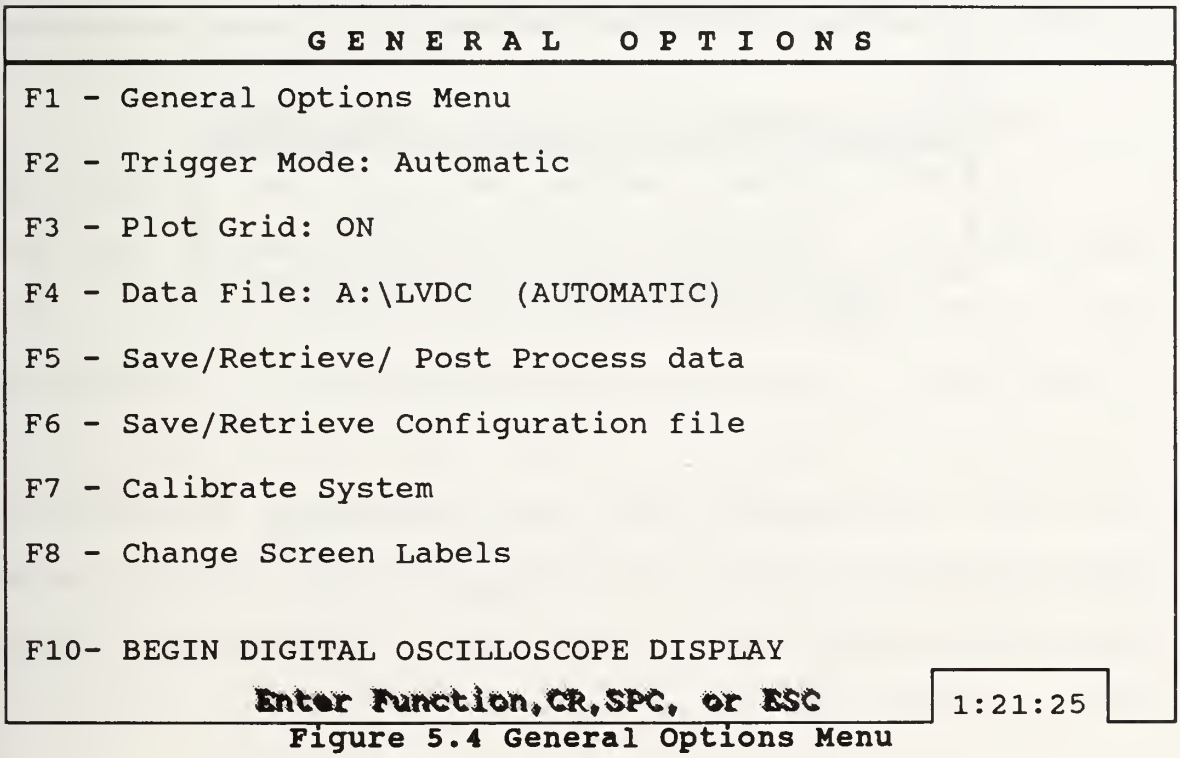
G E N E R A L O P T I O N S
F1 - General Options Menu
F2 - Trigger Mode: Automatic
F3 - Plot Grid: ON
F4 - Data File: A:\LVDC (AUTOMATIC)
F5 - Save/Retrieve/ Post Process data
F6 - Save/Retrieve Configuration file
F7 - Calibrate System
F8 - Change Screen Labels
F10- BEGIN DIGITAL OSCILLOSCOPE DISPLAY
Enter Function,CR,SPC, or ESC
1:21:25

Figure 5.4 General Options Menu

B. RAPID SYSTEMS R900 FILE TRANSLATION UTILITY

The Rapid Systems R900 File Transition Utility converts data files saved by Rapid Systems' R1405 Digital Oscilloscope into an ASCII format which can be used in PC-MATLAB and Lotus 1-2-3. It is easy to use, requiring only a few simple key strokes. Table 5.2 lists the minimum system requirements. Refer to the operating manual [Ref. 15] for more detailed information on the R900 package.

TABLE 5.2 R900 SYSTEM HARDWARE REQUIREMENTS

-IBM PC, XT, AT, OR Compatible with at least 256 Kbytes of contiguous RAM.
-At least 1 5.25" 360 Kbyte floppy disk drive.

1. R900 File Translation Utility Installation.

The R900 software resides on a 5.25 inch floppy disk (360K density). There are 17 files on the source disk but only the R900.EXE and R900.WKS files are required. The R900.EXE file is the file translation program. The R900.WKS file allows the operator to import data into a Lotus 1-2-3 work sheet. This option will only be used if the operator wishes to perform statistical operations on the raw data using the installed functions of Lotus 1-2-3. Refer to Ref. 15 for further information.

STEP 1. Type **MD\R900 <Enter>**

STEP 2. Type **CD\R900 <Enter>**

STEP 3. Type **Copy A:*.* C:\R900 <Enter>**

STEP 4. Type **R900** to run software. The screen in figure 5.3 will be displayed. The Installation is now complete.

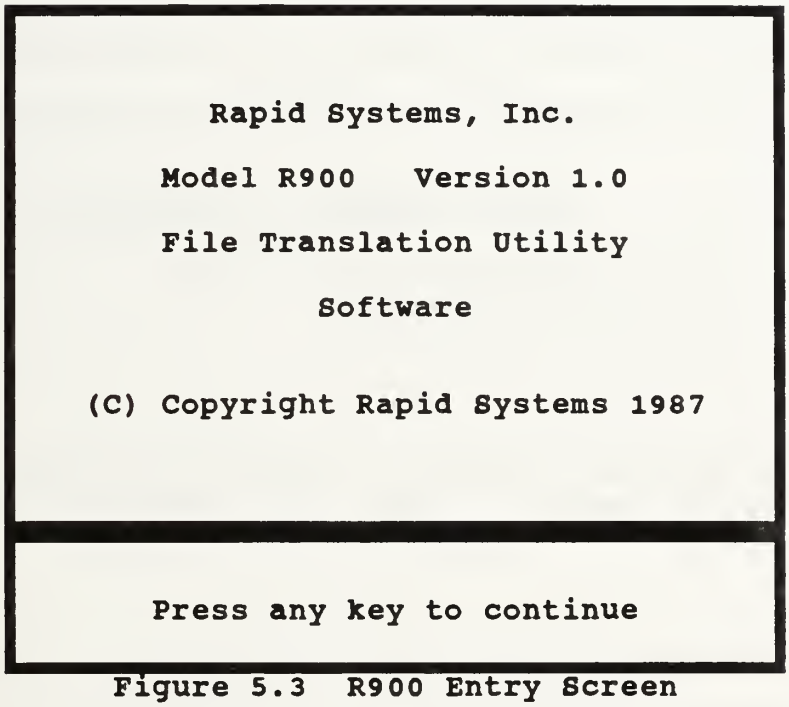

Figure 5.3 R900 Entry Screen

2. R900 File Translation Utility Operation

This section describes the use of the R900 File Translation Utility in the CDSA Test procedure. A more

detailed discussion of the operation of the R900 program may be found in the operators guide [Ref. 12].

The R1405 Digital Oscilloscope will save the data from the test run on a formatted floppy disk in the a drive. The file will be labeled **LVDCXT.DT0** where the *X* represents the number of the cycle which is saved (normally a number between 1 and 5). Once the program has been entered, press any key and the screen shown in Figure 5.4 will be displayed.

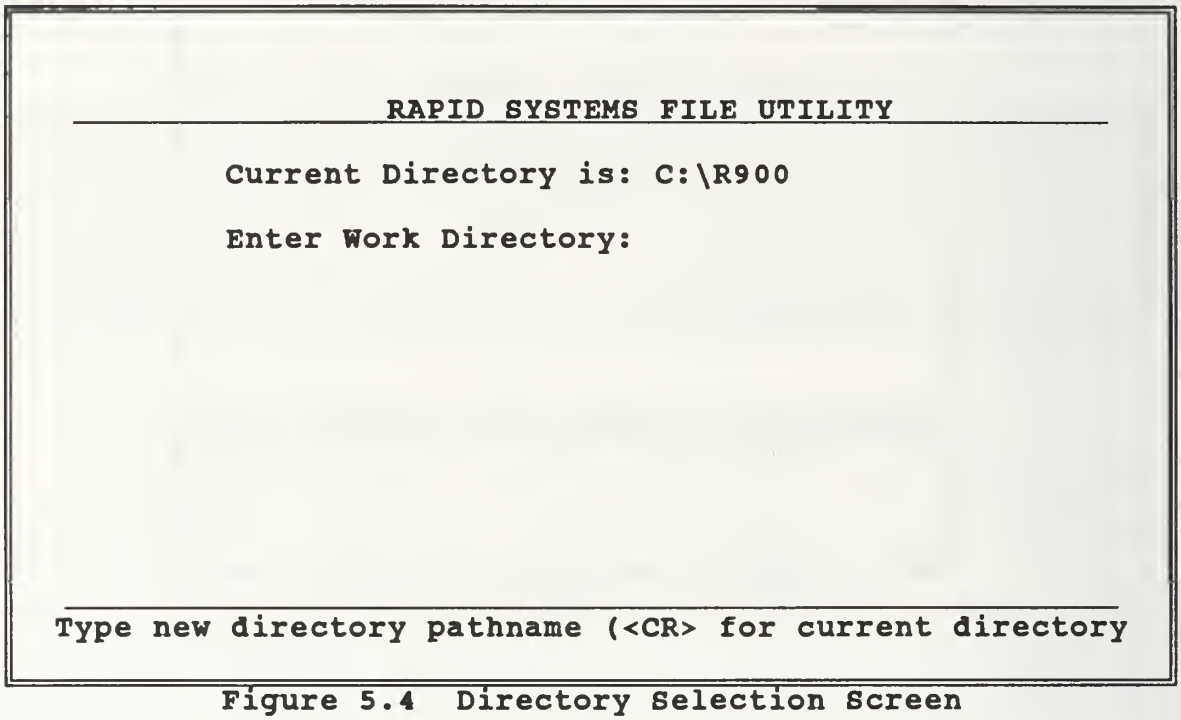
RAPID SYSTEMS FILE UTILITY
Current Directory is: C:\R900
Enter Work Directory:
Type new directory pathname (<CR> for current directory

Figure 5.4 Directory Selection Screen

At this prompt insure the formatted disk with the R1405 data is in the A drive. Type **A: <Enter>** and the screen in Figure 5.5 will appear. Highlight the appropriate file and

press enter. This will cause the output screen, Figure 5.6, to be displayed.

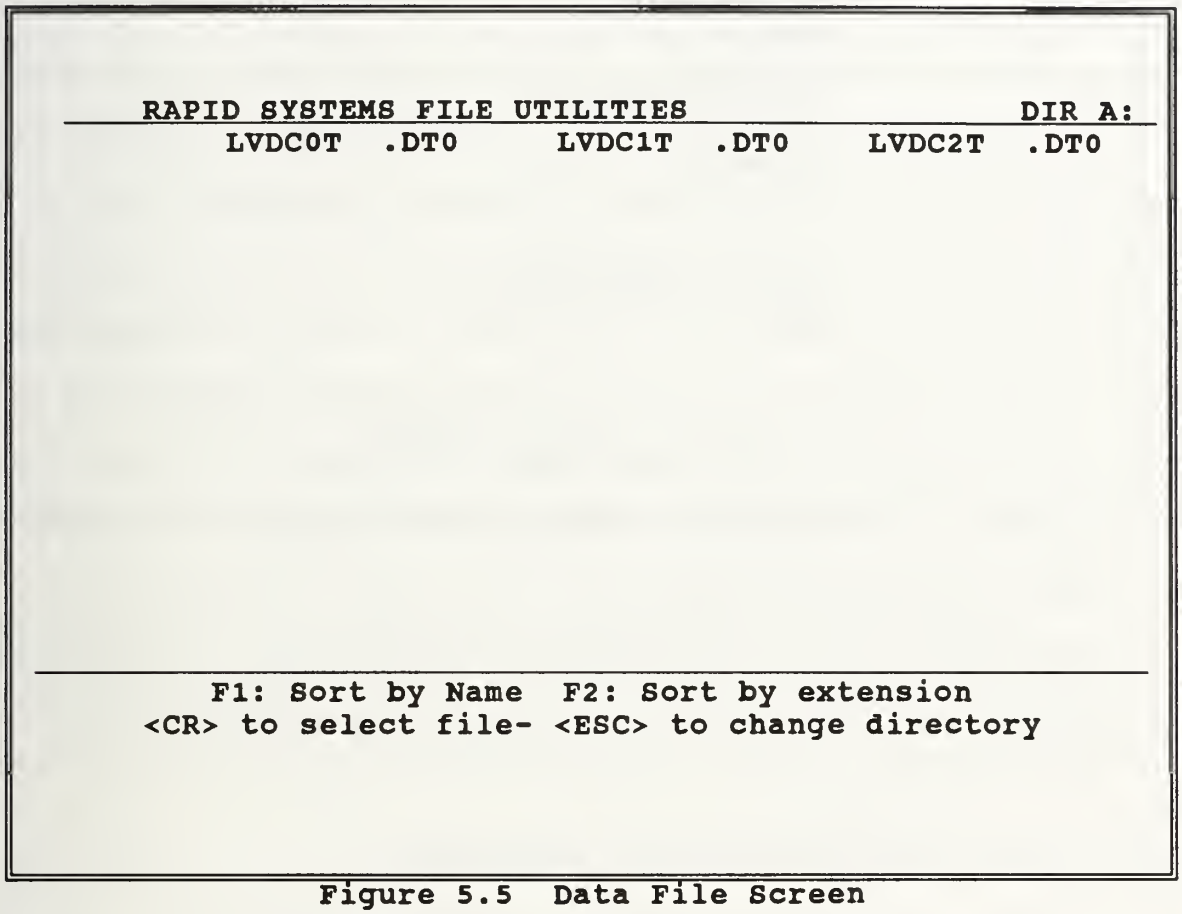
RAPID SYSTEMS FILE UTILITIES DIR A:
LVDC0T .DT0 LVDC1T .DT0 LVDC2T .DT0
F1: Sort by Name F2: Sort by extension
<CR> to select file- <ESC> to change directory

Figure 5.5 Data File Screen

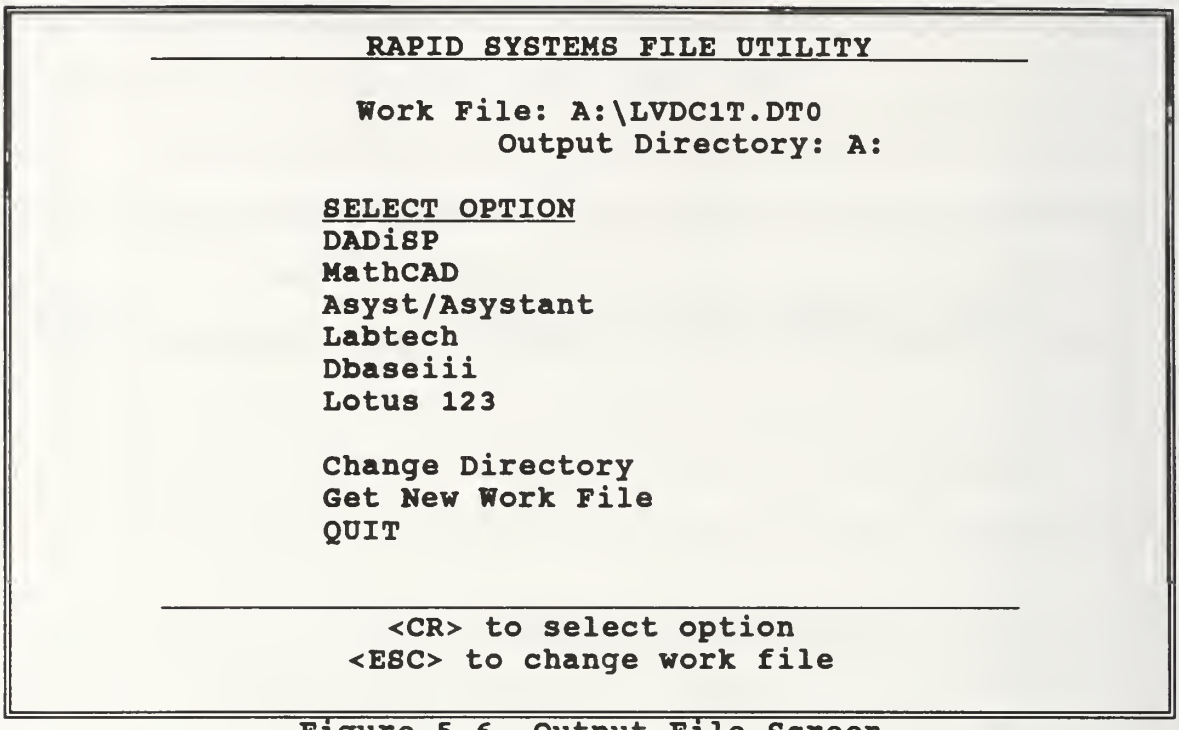

Figure 5.6 Output File Screen

Highlight **MathCAD** and press **<Enter>** this will generate an ASCII file on the disk in the A drive. This file will be named *LVDC.DAT*. Follow the instructions to exit the program.

C. PC-MATLAB TRANSLATE PROGRAM

The PC-MATLAB Translate Program is supplied with the MATLAB Utility Library. The translate program converts ASCII flat files to the special MAT-files used by MATLAB. It will also perform the reverse translation. This method is best if a large amount of data is available in a disk file. Information on installation may be found in the PC-MATLAB Operators Guide [Ref. 13].

This section describes how to translate the ASCII output data of the digital oscilloscope into a MAT-file. This is the data that was translated by the R900 translation Utility and saved on a floppy disk. It is essential that the operator insures that the correct disk is located in the A: drive prior to commencing the process.

The PC-MATLAB translation utility is located in the same directory as the PC-MATLAB program. It is accessed by typing **CD:\MATLAB** followed by **TRANSLATE**. The operator will be asked to provide the name of the input file, the type of input file, the desired output file, the format of the input data, the output file name, and the PC-MATLAB variable. An example run may be found in Figure 5.7. The required operator input is indicated in **bold print**. Information in [ ] represent the default values.

```
<PC-MATLAB TRANSLATION UTILITY>
(c) Copyright  The Mathworks, Inc. 1984, 1986, 1987
All Rights reserved
Version 1.21 13-Jun-87


Input file name:  A: lvdc.dat <Enter>

Available input file formats are:
        1 - ASCII (flat)
        2 - PC-MATLAB
        3 - Fortran unformatted (Microsoft Fortran)
        4 - Binary stream
        5 - DIF (Data Interchange Format)

Format number for input data [1]:   1 <Enter>

Available ASCII options are:
        Number of columns [to newline]
        Number of rows [to end of file]

Changes  (y/n)? [n]:  y <Enter>

Number of columns [to newline]: 1 <Enter>

Number of rows [to endfile]:  2048 <Enter>

Available output file formats are:
        1 - ASCII (flat)
        2 - PC-MATLAB
        3 - Fortran unformatted (Microsoft Fortran)
        4 - Binary stream
        5 - DIF (Data Interchange Format)

Format number for output data [2]: 2 <Enter>

Output file name [lvdc.mat]:  <Enter>

PC-MATLAB variable name [lvdc]:  <Enter>
```

Figure 5.7 PC-MATLAB Translation Utility Example Run

The PC-MATALB file and variable are now stored in the PC-MATLAB directory and analysis may begin using the CDSA test program to be covered in the next section. Additional information may be found in the PC-MATLAB Operators Guide.

D. PC-MATLAB PROGRAM AND TEST PROGRAM

This section gives a brief description of the PC-MATLAB program and describes its application as part of the CDSA. Information on installation and setup of the PC-MATLAB program are contained within the operators guide. Hardware requirements for PC-MATLAB are contained in Table 5.3.

TABLE 5.3 PC-MATLAB SYSTEM HARDWARE REQUIREMENTS

- IBM PC, XT, AT or compatible with 1 5.25 inch floppy drive and 640 Kbytes of contiguous memory
- MATH CO-PROCESSOR
- 5 Mbyte available on Hard Drive
- CGA, VGA, or EGA Color Monitor or equivalent

PC-MATLAB is a mathematical program which will perform operations on matrices. PC-MATLAB is well suited for

engineering applications due to the extensive function library. It also has graphical functions which allow the operator to display data in a variety of formats.

PC-MATLAB comes with an extensive *function library*, containing the most common operators used in mathematics, statistics, and engineering. A *function* is a mathematical operator which manipulates the data contained in the *rectangular numerical matrix* to yield information about the data set contained within. The *function library* can be customized by combining several of these *functions* to obtain the desired operation. This allows the programmer to generate extremely complicated operations and execute them by typing only one word.

The PC-MATLAB program, which was written for the CDSA, is composed of several complicated functions designed to extract statistical and frequency information from the data originally obtained from the oscilloscope program. These functions are contained on a separate floppy disk, and are copied directly into the PC-MATLAB directory.

1. CDSA Record of Test Form

It is recommended that a written record be maintained for each test. A sample record sheet is shown in Figure 5.8. The required information includes, unit identification data, rectifier identification data, operating hours since last test, technician identification data, and information on the

input voltage. These records should be maintained on board for each rectifier.

USS OHIO (SSBN 726)
LVDC RECTIFIER TEST RECORD FORM

UIC:	RECTIFIER SERIAL #:	DATE:
OPERATING HOURS:	GENERATOR FREQ:	GENERATOR VOLTAGE:
CURRENT:	NAME:	RATE:
AUTHORIZATION:	TEST START TIME:	TEST END TIME:

PARAMETER	RESULT	PARAMETER	RESULT
DC VOLTAGE		180 HARM DIST	
RIPPLE VOLTAGE		180 HARM DIST	
SKEWNESS		180 HARM DIST	
KURTOSIS		300 HARM DIST	
60 Hz HARMONIC		300 HARM DIST	
120 Hz HARMONIC		60 PSD	
180 Hz HARMONIC		120 PSD	
240 Hz HARMONIC		180 PSD	
300 Hz HARMONIC		240 PSD	
360 Hz HARMONIC		300 PSD	
TOT HARM DIST		360 PSD	

COMMENTS: _____

_____

_____

_____

Figure 5.8 Sample Record of Test Form

2. Test Program Operation

To enter the PC-MATLAB program type **MATLAB <Enter>** while in the PC-MATLAB directory. To begin the test procedure type **TEST <Enter>.** An entry screen will be displayed instructing the operator to *Press <Enter> to Continue*. Type **<Enter>** to perform a check on the format of the input data set. The dimensions of the data file will be displayed first. If the numbers *{2048 1}* appear, then the data set has the proper dimensions. To continue the test type **<Enter>** and record the result. Continue in this fashion until all the parameters have been recorded. To check the recorded values type **DATA2** and the numerical values will appear in a row vector format. These values have been saved in a PC-MATLAB formatted file called *DATA2.MAT*. This file will have to be translated into an ASCII file format for storage and further analysis in Lotus 1-2-3. The process is simply the reverse of the translation described in Figure 5.7. Figure 5.9 describes the process. To exit the test program type **exit.**

The *DATA2.MAT* file will have to be translated to an ASCII format on a floppy disk using the PC-MATLAB Translate Utility. Each time this program is run this file is erased, making it necessary to save these results prior to commencing the next test. It is recommended that one floppy disk be used for each test, labeled, and stored in a safe place. The test program may be found in the Appendix.

```
          <PC-MATLAB TRANSLATION UTILITY>
(c) Copyright  The Mathworks, Inc. 1984, 1986, 1987
                All Rights reserved
              Version 1.21 13-Jun-87


Input file name:  DATA2.MAT <Enter>

Available input file formats are:
        1 - ASCII (flat)
        2 - PC-MATLAB
        3 - Fortran unformatted (Microsoft Fortran)
        4 - Binary stream
        5 - DIF (Data Interchange Format)

Format number for input data [1]:   2 <Enter>

Available variables are:
        PSD 60
        PSD 120
        D
        DATA2

Variable name [name]: data2 <Enter>


Available output file formats are:
        1 - ASCII (flat)
        2 - PC-MATLAB
        3 - Fortran unformatted (Microsoft Fortran)
        4 - Binary stream
        5 - DIF (Data Interchange Format)

Format number for output data [2]: 1 <Enter>

Output file name [data2.dat]:  A:data2.dat <Enter>
```

Figure 5.9 ASCII Translation Example Run

E. LOTUS 1-2-3 APPLICATIONS

Lotus 1-2-3 offers facilities for numerical calculations, graphics, and programmability in a single, easy-to-use package. This section describes spread sheet design, data input, and regression analysis. A Lotus 1-2-3 spread sheet, with all the parameters listed would, not fit on a standard sheet of paper. For demonstration purposes, all examples in this section will use three parameters, operating hours, DC voltage, and Ripple Voltage. This section is not intended to be a tutorial on Lotus 1-2-3, but explains its applications for this test procedure. *The Student Edition of Lotus 1-2-3 Second Edition* [Ref. 14] is an excellent reference and tutorial.

1. Spread Sheet Design

The spread sheet will contain information on the 22 monitored parameters, operating hours, and the date. Additionally there will be regression analysis data, and labelling information. Figure 5.10 gives a recommended spread sheet layout. Specific information on enhancing spread sheet appearance may be found in *1-2-3 For Scientist and Engineers* and *1-2-3 Tips, Tricks, and Traps* [Ref. 15]. Once the design is created and saved, it is only a matter of a few key strokes to recall it and update it.

DATE	OPERATING HOURS	DC VOLTAGE	RIPPLE VOLTAGE
10-Feb-90	200.000	28.500	0.300
10-Mar-90	275.000	28.200	0.600
10-Apr-90	340.000	27.950	0.700
10-May-90	400.000	28.200	0.800
10-Jun-90	405.000	29.100	0.400
10-Jul-90	425.000	28.700	0.600
10-Aug-90	430.000	28.300	0.900
10-Sep-90	500.000	29.700	0.800
10-Oct-90	525.000	30.000	0.700
10-Nov-90	600.000	30.100	1.000
10-Dec-90	602.000	29.600	0.900
10-Jan-91	619.000	29.000	1.000
10-Feb-91	620.000	28.200	0.950
10-Mar-91	700.000	29.300	0.800
10-Apr-91	712.000	27.600	1.000
10-May-91	780.000	28.000	0.900

Figure 5.10 Lotus 1-2-3 Spread Sheet for CDSA

2. Data Input

The two methods of Data Input available for our use are direct input of the **DATA2** variable using the **File Import** command or manual input from the record sheet. The **File Import** will require the operator to also use the **Data Parse** command to format the data. For someone unfamiliar with Lotus 1-2-3 manual entry from the record sheet may be the easiest method.

3. Regression Analysis

Lotus 1-2-3 has a built-in *multiple linear regression* function. With this capability data can be fit to either a simple line or a complicated polynomial. For simplicity, and ease of use, only the linear regression capability will be used. This will allow the technician to analyze any trends which may be present and predict an impending system failure. In the remainder of this section *linear regression analysis* will be performed on the data in Figure 5.10. This same process could be performed on any of the parameters using the same procedure.

For this procedure it is assumed that the information has already been input, and is arranged a fashion similar to Figure 5.10. *Operating Hours* will always be the independent variable labeled as the *X*-variable for regression analysis. For this example *Ripple Voltage* will be the dependent variable labeled as the *Y*-variable for analysis. Any of the parameters could be analyzed in a similar fashion.

STEP 1. Type / to display the options menu figure 5.11.

Worksheet Range Copy Move Print Graph Data System Quit

Figure 5.11 Main Menu

STEP 2. Use -> Arrow key to highlight *Data* as shown in figure 5.12.

Worksheet Range Copy Move Print Graph **Data** System Quit

Figure 5.12 Main Menu

STEP 3. Highlight **Regression** as shown in figure 5.13. This will display the menu in figure 5.14.

Fill Table Sort Query Distribution Matrix **Regression** Parse

Figure 5.13 Data Menu

X-Range Y-Range Output-Range intercept Reset Go Quit

Figure 5.14 Regression Menu

STEP 4. Highlight **X-Range** and mark the data contained in the operating hours column. This is done by identifying the letter of the column and the numbers of the rows containing the data. For example **D6..D22.**

STEP 5. Highlight **Y-Range** and perform the same task for Ripple Voltage.

STEP 6. Highlight **Output-Range** and move mark the cell where The Regression Data can be positioned. For Example **J6.**

STEP 7. Highlight **Go** and the regression data will be anchored at cell **J6.** The regression data for our example may be found in figure 5.15.

Regression Output:	
Constant	0.27218
Std Err of Y Est	0.14039
R Squared	0.58804
No. of Observations	6.00000
Degrees of Freedom	14.00000
X Coefficient (s)	0.00098
Std Err of Coef.	0.00022

Figure 5.15 Sample Regression Data from Data in Figure 5.10

STEP 8. Using equation 4.20 and the values for the constant and the coefficient given above a linear regression graph like the one in figure 5.16 may be generated.

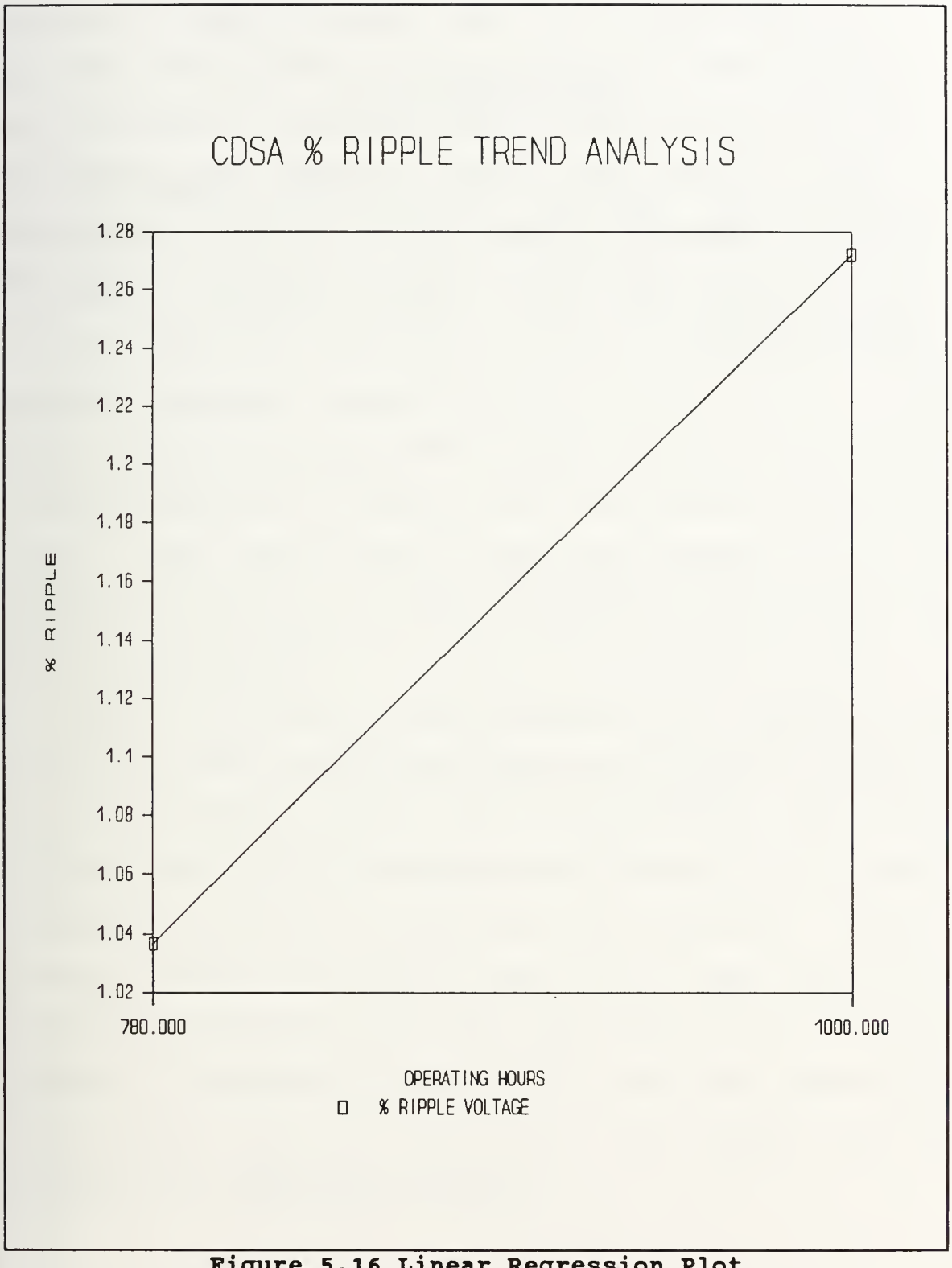

Figure 5.16 Linear Regression Plot

In Figure 5.16 the values for the independent variable, used to plot the graph were 780 and 1000. This was the last actual value for operating hours in figure F.10 and a value in the future picked at random for demonstration purposes. This graph gives an indication that ripple voltage will not exceed the limit for ripple voltage (2%) before 1000 operating hours.

VI. CONCLUSION

The Computerized Diagnostic Analyzer can enhance the information available on the material condition of the Low Voltage DC rectifiers found on Ohio Class Fleet Ballistic Missile Submarines. Frequency information can help identify specific component failures prior to system failure. This system can be implemented with minimal changes in the current test procedure and at minimal cost. This system is relatively easy to use, particularly when one considers that the personnel performing the test have a significant knowledge of math and electronics.

Topics for further study are operational testing of the CDSA under actual conditions, correlation studies to identify the relationships between the 22 parameters and system failure, and analysis to determine the effectiveness of linear regression analysis in predicting system failure. Another possible follow on project would be to apply this test procedure to other DC rectifiers. Many rectifiers in the Navy operate on the same principle, as the rectifier examined in this project, and the low cost of the system makes it practical for these applications.

APPENDIX
COMPUTER CODE

```
%WELCOME TO THE TRIDENT LVDC RECTIFIER TEST SYSTEM.
%
%WARNING! READ AND FOLLOW ALL SAFETY REQUIREMENTS REQUIRED FOR
THIS TEST.
%
%WARNING! FOLLOW ALL PROCEDURES AND SMP INSTRUCTIONS WHEN
PERFORMING TEST.
%
%WARNING! INSURE DISK A CONTAINS CORRECT DISK FOR ANALYSIS
%
%PLEASE INSURE THE FOLLOWING INFORMATION IS RECORDED ON THE
TEST DATA SHEET
%
%
%PRIOR TO BEGINNING TEST.
%1) UNIT IDENTIFICATION NUMBER:
%2) RECTIFIER IDENTIFICATION NUMBER:
%3) DATE AND TIME OF TEST:
%4) SYSTEM OPERATING HOURS SINCE LAST TEST:
%5) GENERATOR FREQUENCY:
%6)  AMMETER  CURRENT  READING  RECORDED  IN  IAW  NAVSEA
ST940-AD-MMA-010
%   AND APPROPRIATE SMP--CURRENT(AMPS):
%7) TECHNICIAN NAME AND RATE:
%8) PERSON AUTHORIZING TEST #:
%**PRESS ENTER TO BEGIN DATA ANALYSIS********************
!cls
load data1
logo
pause
!cls
help test
pause
!cls
help tmess
load data1
[M N]=size(data1')
clear M
help tmess1
help enterm
pause
test1(data1,N);
```

```
%THIS FUNCTION GENERATES THE ENTRANCE GREETING FOR TERRY'S
THESIS
load e
plot(e),title('TRIDENT LOW VOLTAGE POWER SUPPLY SPECTRUM
ANALYSIS PROGRAM'),xlabel('PRESS ENTER TO BEGIN')
clear e

%THIS FUNCTION CALLS THE TEST FUNCTION AND PROVIDES SPACE
%FOR FUTURE PROGRAM ADDITIONS AND MESSAGES
function y=test1(data1,N);
!cls
a=time(data1,N);

%THIS PROGRAM CALCULATES THE 22 PARAMETERS REQUIRED TO BE
CALCULATED FOR
%THE COMPUTERIZED DIAGNOSTIC ANALYZER (CDA).  THIS PROGRAM IS
ENTERED
%THROUGH THE PROGRAMS 'test' and 'test1' WHICH LOAD THE DATA
AND PROVIDE
%THE LOGO.
function y=time(data1,N);
!erase chart1.met
!cls
help please
plot(data1),title('TIME PRESENTATION OF DATA ON "O" SCOPE
'),xlabel('PRESS ENTER TO CONTINUE'), ylabel('DC VOLTS')
meta chart1
pause
!cls
help please
%BEGIN TIME SERIES ANALYSIS**********************************
help mess
help mess1
%CALCULATION OF DC VOLTAGE
DC=mean(data1')
help enterm
pause
b=std(data1');
!cls
help please
help mess2
%CALCULATION OF RIPPLE VOLTAGE*****************
RIPPLE=b
help enterm
pause
```

```
!cls
help please
help mess3
%CALCULATION OF VARIANCE**********************
VARIANCE=b^2
help enterm
pause
!cls
help please
for i=1:N
s(i)=((data1(i)-DC)/RIPPLE)^3;
end
help mess4
%CALCULATION OF SKEWNESS**********************
SKEWNESS=(1/N)*sum(s)
clear b
clear s
help enterm
pause
!cls
help please
for i=1:N
k(i)=((data1(i)-DC)/RIPPLE)^4-3;
end
help mess5
%CALCULATION OF KURTOSIS**********************
KURTOSIS=(1/N)*sum(k)
clear k
help enterm
pause
!cls
help please
%END TIME SERIES ANALYSIS*********************
help mess6
help mess7
%BEGIN FREQUENCY ANALYSIS*********************************
%
%PERFORM FFT TO DETERMINE SPECTRUM*************
help mess7a
DATA1=abs(fft(data1'));
clear data1
%ISOLATE HARMONICS OF 60 Hz*********************
SCALE=max(DATA1);
for i=1:N/2
freq(i)=(i-1)*1000/2048;
if i>116 & i<129
```

```
X1(i-115)=DATA1(i);
end
if i>233 & i< 258
X2(i-232)=DATA1(i);
end
if i>350 & i< 387
X3(i-349)=DATA1(i);
end
if i>466 & i< 516
X4(i-465)=DATA1(i);
end
if i>584 & i< 645
X5(i-583)=DATA1(i);
end
if i>701 & i< 774
X6(i-700)=DATA1(i);
end
end
for i=1:N/2
DATA(i)=DATA1(i);
end
plot(freq,20*log(DATA)), title('SPECTRUM OF INPUT DATA'),
xlabel('FREQUENCY IN HZ        PRESS ENTER TO CONTINUE'),
ylabel('DECIBELS')
pause
!cls
help please
clear DATA
help mess8
%DETERMINE MAGNITUDE OF HARMONICS OF 60 Hz*****
H60=max(X1)*100/SCALE
help enterm
pause
!cls
help please
help mess8
H120=max(X2)*100/SCALE
help enterm
pause
!cls
help please
help mess8
H180=max(X3)*100/SCALE
help enterm
pause
!cls
```

```
help please
help mess8
H240=max(X4)*100/SCALE
help enterm
pause
!cls
help please
help mess8
H300=max(X5)*100/SCALE
help enterm
pause
!cls
help please
help mess8
H360=max(X6)*100/SCALE
help enterm
pause
!cls
help please
help mess8
%DETERMINE TOTAL HARMONIC AMPLITUDE OF 60 HZ****
HTOT=H60+H120+H180+H240+H300+H360
help enterm
pause
!cls
help please
help mess9
%DETERMINE HARMONIC DISTORTION******************
TOTDISTORTION=sqrt((H120^2+H180^2+H240^2+H300^2+H360^2)/(H60
^2))*100
help enterm
pause
!cls
help please
help mess10
DISTORTION120=100*sqrt((H120^2)/(H60^2))
help enterm
pause
!cls
help please
help mess10
DISTORTION180=100*sqrt((H180^2)/(H60^2))
help enterm
pause
!cls
help please
```

```
help mess10
DISTORTION240=100*sqrt((H240^2)/(H60^2))
help enterm
pause
!cls
help please
help mess10
DISTORTION300=100*sqrt((H300^2)/(H60^2))
help enterm
pause
!cls
help please
help mess10
DISTORTION360=100*sqrt((H360^2)/(H60^2))
help enterm
pause
!cls
help please
clear X1
clear X2
clear X3
clear X4
clear X5
clear X6
clear DATA1
help mess11
%DETERMINE PERIODOGRAM AT HARMONICS***********
PSD60=20*log((1/N)*H60^2)
help enterm
pause
!cls
help mess11
PSD120=20*log((1/N)*H120^2)
help enterm
pause
!cls
help mess11
PSD180=20*log((1/N)*H180^2)
help enterm
pause
!cls
help mess11
PSD240=20*log((1/N)*H240^2)
help enterm
pause
!cls
```

```
help mess11
PSD300=20*log((1/N)*H300^2)
help enterm
pause
!cls
help mess11
PSD360=20*log((1/N)*H360^2)
help enterm
pause
!cls
%SAVE PARAMETERS TO A VECTOR*******************
D(1)=DC;
D(2)=RIPPLE;
D(4)=SKEWNESS;
D(5)=KURTOSIS;
D(6)=H60;
D(7)=H120;
D(8)=H180;
D(9)=H240;
D(10)=H300;
D(11)=H360;
D(12)=DISTORTION120;
D(13)=DISTORTION180;
D(14)=DISTORTION240;
D(15)=DISTORTION300;
D(16)=DISTORTION360;
D(17)=PSD60;
D(18)=PSD120;
D(19)=PSD180;
D(20)=PSD240;
D(21)=PSD300;
D(22)=PSD360;
data2=D;
save data2
%********END OF PROGRAM*********************
help mess13

enterm-%RECORD RESULTS AND PRESS ENTER TO CONTINUE WITH TEST

please-%PLEASE WAIT WHILE I THINK
```

```
mess1- %RANGE FOR DC VOLTAGE IS 24 TO 36 Vdc
mess2- %MAXIMUM LIMIT FOR RIPPLE VOLTAGE IS 2 PERCENT
mess3- %MAXIMUM FOR VARIANCE IS 4
mess4- %SKEWNESS HAS NO NORMAL RANGE DEFINED AT THIS TIME
mess5- %KURTOSIS HAS NO NORMAL RANGE DEFINED AT THIS TIME
mess6- %COMPLETION OF TIME SERIES ANALYSIS
mess7- %COMPLETION OF TIME SERIES ANALYSIS
mess8- %AMPLITUDES OF HARMONICS OF 60Hz, 120Hz, 180Hz,
       240Hz, 300Hz, 360Hz
       %MAXIMUM LIMIT FOR THIS PARAMETER HAS NOT BEEN
       DETERMINED
       %RESULTS ARE IN % OF DC COMPONENT [HARMONIC/DC]*100
mess9- %MAXIMUM IS 5% FOR TOTAL HARMONIC DISTORTION
mess10-%MAXIMUM OF HARMONIC DISTORTION FOR SINGLE HARMONIC
       IS 3%
mess11-%RESULTS FOR POWER SPECTRAL DENSITY ARE IN DECIBELS
       [20*log(PSD)]
       %THE LIMIT FOR THIS PARAMETER HAS NOT BEEN
       DETERMINED
mess12-%5 0F 5 PERIODOGRAMS HAVE BEEN CALCULATED
mess13-%THIS CONCLUDES THE MATLAB PORTION OF DATA ANALYSIS
       %************************************************
       %
       %
       %ALL PARAMETERS ARE SAVED IN A VARIABLE NAMED
       'data2'
       %
       %
       %************************************************
       %PLOTS PRODUCED DURING TEST MAY BE PRINTED OUT
       USING 'graph chart1'
       %COMMAND AFTER MATLAB PROGRAM HAS BEEN EXITED
       %TYPE 'exit' TO EXIT MATLAB PROGRAM
mess14-%MAXIMUM FOR ALL HARMONICS OF 60 HZ
       (60,120,180,240,300,360) IS 2%
mess15-%MAXIMUM FOR HARMONIC DISTORTION IS 2.8%
mess16-%ALL NUMERICAL VALUES ARE SAVED IN THE VARIABLE
       'data.mat'
       %WHICH HAS BEEN SAVED ON THE HARD DRIVE
       %IT MUST BE TRANSLATED INTO ASCII CODE PRIOR TO USE
       %IN LOTUS 1-2-3 UTILIZING THE PCMATLAB TRANSLATION
       PROGRAM
       %IT MUST THEN BE SAVED ON A FORMATTED FLOPPY IN THE
       A DRIVE
       O' SCOPE GRAPH CAN BE PRINTED OUT BY TYPING 'GRAPH
       CHART1'
       %PERIODOGRAM GRAPH CAN BE PRINTED OUT BY
       TYPING 'GRAPH CHART2'
```

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